Appendix E

Hydropower Simulation

The basic operation of HEC-5 hydropower routines is to find the necessary release to generate a specified energy requirement. This exhibit describes HEC-5 hydropower operation and the data required for the various program options. The basic hydropower reservoir is described first, followed by additional program features for: pump-storage, hydropower optimization, system power, added turbine units, energy benefits.

E.1 Power Operation

For hydropower operation, the program computes the energy requirements for each time period-of-operation. The monthly energy requirements and distributions or the period-by-period energy requirements are used for this purpose.

The program cycles through the simulation one interval at a time. For the hydropower reservoirs, the following logic is used to determine a power release:

1. Estimate average storage. Use end of previous period's storage initially and then the average of computed and end-of-period storages. (Reservoir elevation and evaporation are both dependent on average storage.)

2. Estimate tailwater elevation. Use highest elevation from block loading tailwater, or tailwater rating curve, or downstream reservoir elevation.

3. Compute gross head by subtracting tailwater from reservoir elevation corresponding to estimated average storage.

4. Compute reservoir release to meet energy requirement.

$$Q = \frac{Ec}{eht} \qquad \textbf{(E-1)}$$

where:

E	=	required energy (kWh)
c	=	conversion factor - (11.815 English or 0.102 metric)
e	=	plant efficiency
h	=	gross head (feet English or meters)
t	=	time (hours)
Q	=	reservoir release

5. Compute reservoir evaporation (EVAP) using reservoir area based on average reservoir storage.

6. Solve for ending storage (S_2) using continuity equation:

$$S_2 = S_1 - EVAP + (INFLOW - OUTFLOW) \bullet CQS \quad \textbf{(E-2)}$$

where:

S_1	=	end-of-period storage
EVAP	=	evaporation during time interval
OUTFLOW	=	power release and leakage
CQS	=	discharge to storage conversion

7. On the first cycle, use the new S_2 and return to 1. On subsequent cycles, check the computed power release with the previous value for a difference less than 0.0001. Use up to five cycles to obtain a balance.

8. Check maximum energy that could be produced during time interval using overload factor and installed capacity.

9. Check maximum penstock discharge capacity, if given. Reduce power release to penstock capacity if computed release exceeds capacity.

The program will also determine if there is sufficient water in storage to make the power release. The buffer pool is the default minimum storage level for power; however, the user can define the inactive pool as the minimum power pool. If there is not sufficient water in storage, the program will reduce the release to just arrive at the minimum pool level. If there is sufficient water, the power release for the reservoir establishes a minimum flow at that site. Other considerations are described in the section on Hydropower Limits.

E.2 Hydropower Data

Power data are input with reservoir data at each hydropower reservoir. The basic data requirements include: energy requirements, installed capacity, an overload ratio, a combined turbine-generator efficiency, tailwater elevation, and optional losses and penstock capacity. Example data are shown in Section E.3.

E.2.1 Energy Requirement Options

At-site energy requirements may be expressed by two basic methods: firm energy or non-firm energy. Firm energy requirements are generally given in thousand kilowatt-hours (MW-hr) per month or as monthly plant factors (ratios of the portion of the month the plant is generating). If the simulation is daily or multi-hourly, the ratio of the monthly value is given for each time interval.

An alternative to the firm energy method of operation is the use of project guide curve. The curve defines the plant factor as a function of the percent of power storage occupied in the reservoir during any time period.

Monthly Firm Energy Requirements. The conventional way to express an energy requirement is to specify a monthly at-site firm energy requirement in MW-hr. The first monthly value is for the starting month, typically January (**J1**, field 2). The monthly energy requirements are defined sequentially on the **PR** Records.

For run-of-river projects there is typically no energy requirement; however, the **PR** Records are still required. For a run-of-river model, the monthly energy requirement data on the two **PR** Records would be set to zero.

Monthly Plant Factors. An alternate means of specifying an energy requirement is by monthly plant factors. The plant factor is based on operating at installed capacity for a portion of time. The energy requirement in kWh is computed as follows:

$$\text{Energy (kWh)} = \text{Plant Factor} * \text{Installed Capacity (kW)} * \Delta\text{Time (hours)}$$

Monthly plant factors are specified on the **PR** Records as negative decimal values. The negative sign indicates that these values are plant factors and not fixed energy requirements (in MW-hr).

Note: When plant factors are input and a variable capacity is defined (**PP** and **PS** Records), the program will used the *Installed Capacity* to determine the *Energy Required*; however, the *Energy Generated* will be limited to the *Plant Factor* times the *Current Capacity*. Therefore, there will be energy shortages when the capacity drops below the installed value. The use of plant factors assumes a "Peaking" operation where the plant is on a fixed length of time in the day.

The output values of plant factor, labeled "PLANT FA", are the plant factor computed from the final release, and may differ from the required plant factor for a particular period. During the periods the reservoir is operating for at-site power (Case = .10) the plant factor shown in the output should be the same as that given in the input (**PR** data). However, during periods when a higher reservoir release is made to draw to the top-of-conservation pool (e.g., Case = .03) the plant factor is computed as follows:

$$\text{Plant Factor (Final)} = \frac{\text{Energy generated (kWh)}}{\text{Capacity (kW) x time (hours)}}$$

Higher reservoir release generates more energy resulting in a higher plant factor.

E.2.2 At-Site Energy Distribution

Monthly energy requirements can be distributed on a daily schedule and an hourly schedule. The daily schedule is given on the **PD** Record and it indicates the ratio of weekly energy required each day of the week, Sunday through Saturday. The sum of the ratios should equal one. The daily energy is computed by the following:

Weekly Energy = Monthly Energy * [(7 days/week) / (days in month)]

Daily Energy = Weekly Energy * Day Ratio

The daily distribution would be used for simulation time intervals of 24 hours, or less. The simulation interval is given on the **BF** Record in field seven.

Multi-hourly simulations are useful to obtain a more detailed simulation of project operation. The **PD** Record specifies the daily ratios and the **PH** Record specifies ratios of the daily energy requirement for each time interval within a day. The **PH** Record contains the number of values necessary to cover the number of simulation periods in one day (e.g., four ratios for each six-hour simulation interval). The first value represents the period starting at midnight. The sum of the values equals one.

A maximum of 24 hourly values can be input on the **PH** Record. If the simulation time interval is greater than the **PH** time increment, the program will sum the **PH** values to equal the simulation interval. Therefore, an hourly distribution of daily energy can be used with any even multiple-hour subdivision of a day.

E.2.3 Power Guide Curve

Another style of operation is to apply a power guide curve which relates plant factor to the percent of power storage remaining in the reservoir. This method is an alternative method to firm energy operation. Figure E.1 demonstrates this option graphically. The plant factors are in percent.

The power guide curve relates the power storage occupied at any given time to the plant factor. The end-of-period storage from the previous period will be used to find the required plant factor for the present period.

In Figure E.1, the power pool is defined as the storage between the top-of-the buffer pool (level 2) and the top-of-the conservation pool (level 3). The storage in levels 2 and 3 can remain constant with time, or vary monthly or seasonally. Between levels 2 and 3, the power plant is operated according to the power guide curve. As the pool level increases, the energy requirement increases from a plant factor of 0.1 to a value of 1.0 at full pool, the factors are shown as percent.

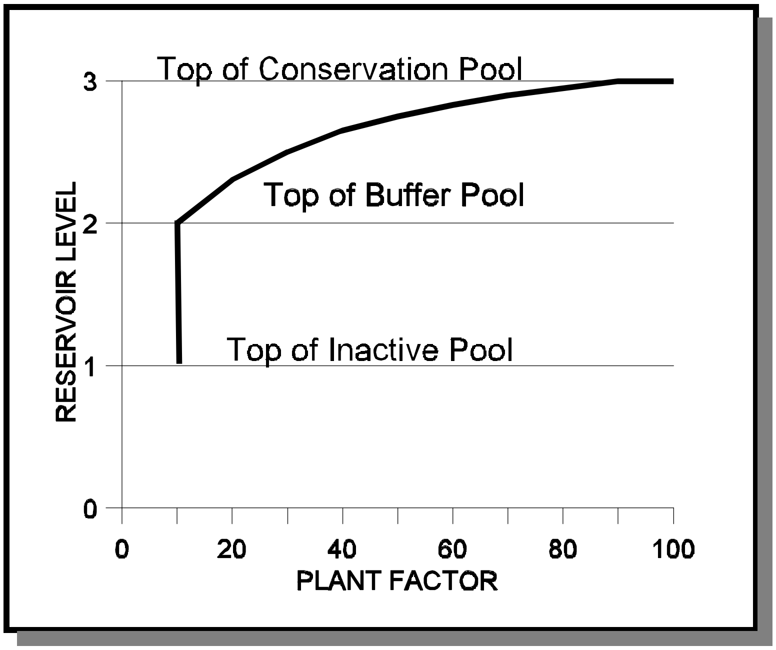

Figure E.1. Power Guide Curve

The reservoir storage between the inactive and buffer levels (levels 1 and 2) will also be used to generate power, but at a minimum plant factor corresponding to 0% power storage on the guide curve, unless the Power Drawdown Priority is used. Above level 2, the operation will be governed by the guide curve.

The HEC-5 input requirements for this option are described below:

Power guide curve. The percent of power storage occupied (expressed as a decimal) is entered on the **PC** Record and the corresponding plant factors are entered on the **PF** Record. Percent power storage should not exceed 1.0 as flood storage will not be counted toward computing an energy requirement for guide curve operation. For this option, the monthly ratios input on the **PR** Record are multiplied by this factor.

Power drawdown priority: The **J2** Record field 4 value includes a 2. This allows the reservoir to draw down to level 1 to generate power.

E.2.4 Power Guide Curve Factor

It is sometimes desired to increase the energy requirements (either firm energy or power guide curve options) when there is sufficient storage in the reservoir to meet the increased requirement. This is handled in HEC-5 through a power guide curve factor. A reservoir power index level may be specified on the **J1** Record in field 9. This is usually the same as the top-of-the buffer pool (level 2), but may be different. Energy requirements can be given as monthly energy requirements (on the **PR** Records) or power guide curve requirements (on the **PC-PF** Records).

The power guide curve factor is entered on field 14 of the **PR** Record. The input energy requirements are multiplied by the factor when the reservoir level, in the previous time period, is above the index level (**J1**.9). For example **PR**.14 = 1.25, then the energy requirement would be multiplied by 1.25 when the reservoir level in the previous period is above the power index level. When the reservoir level drops below the index level, the energy requirements are taken directly from the plant factor specified on the **PC-PF** Records or the energy requirement on the **PR** Records.

E.2.5 Peaking Capability

Hydropower peaking capability may be defined for HEC-5 use in four ways: as a constant capacity value, or a function of: reservoir storage, reservoir release, or power head. The variable peaking capability is used with plants with substantial power storage and provides important information on peaking capability vs. time plus a more accurate estimate of energy.

Constant Capacity. The installed capacity is given on field 2 of the **P1** Record.

Peaking vs. Reservoir Storage. The turbine-generator capability vs. reservoir storage function is input on the **PP** and **PS** Records. A value of 1 is specified in field 4 of the **P1** Record to define this type of relationship. This option is used when head fluctuations are primarily dependent upon the headwater elevation. Note that the end-of-period storage of the previous period is used to determine the peaking capability of the current period. The variable peaking capability in kW is shown in output as "PEAK CAP".

Peaking vs. Reservoir Release. Field 4 of the **P1** Record is changed to 2 to describe the peaking capability vs. reservoir release on the **PP** and **PS** Records. The **PP** and **PS** Records are changed accordingly. This option is used when head fluctuations are primarily dependent upon changes in tailwater. The variation in peaking capability is shown in the column labeled "PEAK CAP".

Peaking vs. Operating Head. Peaking capability vs. reservoir operating head will be read on Records **PP** and **PS** when a 3 is specified in field 4 of the **P1** Record. This option reflects changes in headwater and tailwater elevations, and may be more accurate if both change significantly.

E.2.6 Overload Ratio

An overload ratio is used along with the installed capacity to determine the <u>maximum energy</u> the power plant can produce in a time interval. Many older plants have been designed with an overload ratio of 1.15, meaning that the plant can generate at 15% over installed (nameplate) capacity. The overload ratio is input in field 3 of the **P1** Record. Current Corps' specifications and modern electrical design permit new plants to have a 1.0 overload ratio.

E.2.7 Efficiency Options

There are four ways to express the turbine-generator efficiency in HEC-5. In preliminary studies to determine the hydropower potential at a reservoir, a constant turbine-generator efficiency of 86% is often used. In actual operation, however, the turbine-generator efficiency varies throughout its range of operation. There are three ways to specify a variable efficiency.

Constant Efficiency. The constant value is input on field 7 of the **P1** Record.

Efficiency vs. Reservoir Storage. A value of -1 is coded in field 7 of the **P1** Record to indicate that the efficiencies on the **PE** Record will be used with the reservoir storages on the **RS** Record. Note that the efficiencies are specified in decimal form (50% efficiency = .50).

Efficiency vs. Operating Head. For this option, a value of -1 is also coded in field 7 of the **P1** Record. However, this time the values on the **PE** Record are greater than 1 (an impossible efficiency). Both the head and corresponding efficiency are input on the **PE** Record. The value to the left of the decimal point represents the head corresponding to the efficiency which is entered to the right of the decimal point. (e.g., 144.87 would indicate that the power efficiency is 87% at a head of 144.)

Efficiency in kW/ft^3/s vs. Reservoir Storage. A value of -2 is specified in field 7 of the **P1** Record to indicate an efficiency in kW/ft^3/s coefficients are entered on the **PE** Record. Values of kW/ft^3/s are computed for a project by repetitive solution of the energy equation for assumed elevations in the reservoir. This approach was often used for convenient hand calculations of energy. These coefficients correspond to the reservoir storages on the **RS** Record. Energy is calculated as follows:

$$\text{Energy (kWh)} = \text{Flow (ft}^3\text{/s)} * \text{Coefficient (kW/ft}^3\text{/s)} * \text{Time (hours)}$$

E.2.8 Power Head

In computing the energy that can be generated in any time period, the available head is a critical factor. The headwater is determined by averaging the end-of-period (EOP) storage for the current period and the previous period. The storage in a particular time period, t, is determined from the equation:

$$\text{Storage}_t = \text{Storage}_{t-1} - \text{EVAP} + [(\text{Inflow} - \text{Outflow}) * \text{CQS}]$$

where:

EVAP = Net evaporation for the time step
CQS = Discharge to storage conversion factor

The headwater elevation thus must be determined by a trial and error method because it is based on the outflow, which is also unknown. To compute head, the tailwater must be known. There are three ways to define the tailwater elevation in HEC-5. If more than one method is given, the program uses the highest of those specified.

E.2.9 Tailwater

Block-loading Tailwater. The tailwater elevation may be given as a constant. This is often called block-loading because it represents the tailwater elevation based on the discharge required to produce 100% of the installed capacity. For peaking plants, block-loading is the average "on-line" tailwater that would be expected during power generation. The block-loading tailwater elevation is specified in field 5 of the **P1** Record.

Tailwater Rating Curve. For hydropower analysis it is often necessary to specify tailwater elevation as a function of the reservoir release. Usually, the block-loading tailwater elevation is omitted and a rating curve is entered on the **PQ** and **PT** Records. The hydropower release is an average value for the time interval and the rating curve usually represents an instantaneous value. Therefore, the program adjusts the computed power release by dividing it by the plant factor for the time interval to estimate an instantaneous discharge. The estimated instantaneous value is used to determine the tailwater elevation from the input rating.

Downstream Reservoir. Reservoirs are in tandem when they are on the same stream and consecutive. A downstream reservoir's headwater elevation can affect the tailwater elevation of the upper reservoir. The control point number of the downstream reservoir is input in field 6 on the upstream reservoir's **P1** Record. For each period in the simulation, the elevation of the downstream reservoir pool is compared with the tailwater from block-loading or rating curve and the higher of the two is used to compute the head for the upstream reservoir in that period.

Combination Tailwater Data. All the tailwater options can be used at a site. If more than one option is used, the highest elevation in each period is used to compute the head. Combinations may be required for peaking plants to account for high tailwater elevations during flood conditions, or inundation from downstream reservoir pool.

E.2.10 Losses

Efficiency reflects the "losses" in the electrical-mechanical operation for energy generation. Hydraulic losses reflect the hydraulic head loss and the water losses at the site. Hydraulic loss may be expressed as a constant, or varying with reservoir outflow. In addition, a constant leakage (in ft^3/s) may be specified.

Fixed Hydraulic Losses. A constant hydraulic loss is specified in field 8 of the **P1** Record. The input value is subtracted from the final net head calculated during each period. This hydraulic loss option is comparable to the Block-Loading tailwater option. The output "POWER HE" will include the subtracted loss value.

Losses Varying With Release. Hydraulic losses in feet corresponding to power release are specified on the **PQ** and **PL** Records, respectively. The releases are input in increasing order on the **PQ** Record.

Leakage. Water which continuously passes through the wicket gates or under the dam, or through fish ladders or low flow outlets, but cannot be used for power generation is specified as leakage (in flow units) on the **P2** Record in field 1. The leakage will continue even when no power releases are made. Leakage will occur through the entire range of reservoir levels, until Level 1 is reached.

E.2.11 Hydropower Limits

After the energy-release determination has been made, the program will check limitations in the penstock capacity (if defined) the power capability, and the available water for generation. If any of these considerations cause a reduction in the power release, the energy generated will be less than the specified energy requirement. There is no output *Case* to indicate this situation, so the program may still indicate it is operating for hydropower requirement (*Case* = 0.10). The user should check the following limits when there is a power shortage and the *Case* = 0.10.

Capacity Limit. A variable capacity can limit energy production in a time step. The application of that limit depends on how the energy requirement, **PR** data, is defined.

> <u>If the energy requirement is given (MW-hrs)</u>, then the entire simulation time interval is available to generate the required energy. The capacity will be applied for the entire time interval to meet the energy requirement.
>
> <u>If the energy requirement is defined by plant factors</u>, then only the ratio of the time interval is available to generate the required energy.

Penstock Capacity. The penstock conveys water from the outlet at the reservoir into the turbine. For existing plants, the maximum discharge capacity for the penstock must be considered in estimating energy generation. For proposed plants, there may be a design discharge capacity to consider. If no value is specified, the penstock capacity will not be a constraint on power releases.

The penstock capacity is input on the **P2** Record, field 2. The program converts the penstock capacity to an average discharge over the simulation time interval based on the plant factor for that time period. The following equation is used:

Average Power Release (ft^3/s) = Plant Factor x Penstock Capacity (ft^3/s)

If the computed power release exceeds the penstock capacity, another computational iteration is made for that period limited by the penstock capacity.

Overload Capacity. The overload ratio is only used when there is a surplus of water to be released and the program determines the maximum energy that can be produced in the simulation time interval. Any release greater than the flow required to generate the maximum energy is assumed to be Spill. The Maximum energy is computed by:

$$\text{Maximum Energy} = \text{Capacity} * \text{Overload} * \Delta\text{Time (hours)}$$

The capacity is usually the installed capacity. However, if a variable capacity is defined, the current value of the capacity will be used for this computation.

E.2.12 Priority Options

A primary question in the study of a hydropower system is how much energy can be generated. In a multi-purpose system, many variables can create conflicts in operation. There is the available storage for power generation and the use of that storage for other purposes. Then, during high flows, there may be the need to reduce reservoir releases to minimize flooding at downstream locations. A useful feature in HEC-5 is to allow the user to define priorities between competing project purposes.

Normal Priority. In a multi-purpose system that operates for both hydropower and flood control. the "normal priority" is for reservoirs to operate for flood protection first, and to meet conservation flows second. Conservation flows include minimum required flows, minimum desired flows, and primary energy releases.

Power releases from the reservoir will be cutback (shorting energy requirements) when any control point in the system which the reservoir operates for is flooding.

Power releases are assumed to meet minimum flow requirements. If the power release is insufficient, the release will be increased to meet the specified minimum requirement. Also, the extra release will be used to generate hydropower up to defined physical limits.

Power Priority. The "priority" variable is on the **J2** Record, field 4. The priority code of 1 specifies preference of primary power releases over flood control releases. With this option, releases are made to meet energy requirements even though the release contributes to downstream flooding.

Power Drawdown Priority. In HEC-5, power releases are normally made as long as the reservoir is above the buffer level (usually level 2). The "drawdown priority" option allows releases to be made down to level 1 to generate primary energy. No energy shortages occur as long as there is sufficient water and capacity.

E.2.13 Additional Hydropower Features

This section describes options that may be very helpful in specialized hydropower studies requiring additional modeling and analysis. Items include adding an additional turbine, energy benefits, pump-storage, optimization, and system power.

Headwater Option. HEC-5 can be used to model the addition of a turbine on a second outlet of an existing hydropower reservoir. For example, if a constant 50 ft^3/s is being released through a low flow outlet, and a second turbine is to be placed at the outlet, the "headwater" option can be used to model the second turbine.

First, a dummy reservoir (e.g., Res. 25) is added to the input data for the second plant. Reservoir data for the dummy reservoir describe a reservoir with the same storage as the power reservoir (e.g., Res. 20). Power data describing characteristics of the second turbine are input at the dummy reservoir. A value of -20 is coded in field 6 of the **P1** Record which tells the dummy reservoir to use the headwater elevation from Reservoir 20. A diversion record is added to reservoir 20 to divert the constant 50 ft^3/s from reservoir 20 to the power plant at reservoir 25. See the **DR** Record for input description. This effectively creates a system with a single operating reservoir and two power outlets.

Energy Benefits. Analyzing the economics of a hydropower plant can be aided by the HEC-5 options which allow project benefits to be computed. The **J4** Record provides capability for energy (fields 7 and 8) and capacity (field 6) benefits for a firm energy operation while the **PB** Record allows energy benefits for the power rule curve type of operation. Given the energy benefit values (in mills/kWh) and the corresponding plant factors, the benefit in dollars is computed for the rule curve operation for each period. Required records are the **PC**, **PF**, and **PB**. Data on the records are the percent conservation storage remaining, plant factor and the corresponding benefit rate, respectively.

E.3 Hydropower Modeling

The hydropower model (Example 7) is a three-reservoir system illustrating three types of hydropower modeling: power guide curve, peaking requirements and run-of-river. The first reservoir, on the west branch, operates based on a power guide curve that defines energy required as a function of conservation storage. The upper reservoir on the east branch only operates for its hydropower based on a monthly energy demand schedule, labeled "Peaking Hydropower". The lower reservoir on the east branch has no energy requirement and operates for low-flow demand, labeled "Run-of-river" hydropower. The following sections described each reservoir’s hydropower input data and then the hydropower operation.

The reservoirs have six levels, with top-of-conservation at level 5 and top-of-buffer pool at level 2. The intermediate level 3 is used to favor one reservoir over the other when operating for downstream low-flow goals. (This is described in the note following Table E.3.) Monthly net-evaporation depths are defined for all reservoirs on the **J6** Records.

E.3.1 Power Guide Curve Data

An alternative to specified energy requirements is the power guide curve data used with Andrew Reservoir, location 80. The data are listed in Table E.1. The reservoir data define a seasonally varying storage for levels 3 and 4 (**RL** Records). The **RO** Record indicates the reservoir operates for downstream location 33. Reservoir outflow capacity (**RQ**), reservoir area (**RA**) and elevation (**RE**) are all defined as a function of storage (**RS**). The **R2** Record indicates a rate-of-change of 10,000 ft^3/s for both increasing and decreasing reservoir releases. The seven seasons are defined on the **CS** Record, at the bottom of the input series.

The power data (**P1** Record, fields 2 - 8) define a 82,000 MW plant, with no overload, peaking capability is a function of operating head, no minimum tailwater or downstream reservoir effecting tailwater, efficiency defined by kW versus release based on reservoir storage, and a hydraulic head loss of 1.2 feet. The optional **P2** Record indicates a leakage of 1.5 ft^3/s and a penstock capacity of 9,800 ft^3/s.

Following the **P1** and **P2** Records, are the power rule curve data. This approach defines the energy required as a function of storage available. The **PC** Record defines the percent of power (conservation) storage for the associated power requirements, defined as plant factors on **PF** Records. The first field indicates the number of values, 8. Then the ratios of power storage, from 0 to 1.0 are defined on the **PC** Record and the associated plant factors are defined on the **PF** Record. For example, for a power-storage ratio from 0.0 to 0.45, the energy required is a minimum 0.045 which is equivalent to one hour of generation per day.

Table E.1 Power Guide Curve Input Data (Example 7, beginning of file)

```
T1      HEC-5 Example 7, Basic Hydropower Model   (EXAMPLE7.DAT)
T2      2 Peaking Plants and a Reregulation Reservoir with Run-of-River Power
T3      Green River, Adam Reservoir to Willeyburg, Hourly Flow Data 1986-1987
J1     0       1       6       4       5       2
J2    24       1
J3     4                                       1
J6  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
J6  -0.8    -1.6
J8 80.12   80.10   55.12   55.10   50.12   50.10   33.04   33.05
J8 80.12   80.10   80.13   80.16   80.15   80.35
J8 55.12   55.10   55.13   55.16   55.15   55.35
J8 50.12   50.10   50.13   50.16   50.15   50.35
C =================== Andrew Reservoir (Peaking Project) =====================
RL    80  345000
RL     1      80      -1          82890
RL     2      80      -1          95000
RL     3      80       7         210400  210400  379600  379600  379600  210400
RL                               210400
RL     4      80       7         210492  210492  379611  379611  379611  210492
RL                               210492
RL     5      80      -1         670052
RL     6      80      -1         804006
RO     1      33
RS    32   10373   82884   89647  104879  113447  122709  132705  143514  155137
RS167612  181000  195280  210492  226656  243772  261860  280940  301031  322154
RS344288  367473  391749  417136  443713  471559  500734  531317  563427  597164
RS632646  670052  804006
RQ    32    9800    9800    9800    9800    9800    9800    9800    9800    9800
RQ  9800    9800    9800    9800    9800    9800    9800    9800    9800    9800
RQ  9800   15000   26000   37000   50000   66000   82000  100000  120000  140000
RQ160000  185000  300000
RA    32     182    3251    3516    4116    4452    4812    5196    5602    6024
RA  6462    6913    7373    7841    8317    8801    9293    9793   10298   10808
RA 11329   11862   12411   12988   13599   14246   14933   15665   16449   17293
RA 18206   19201   24200
RE    32     725     800     802     806     808     810     812     814     816
RE   818     820     822     824     826     828     830     832     834     836
RE   838     840     842     844     846     848     850     852     854     856
RE   858     860     870
R2 10000   10000
C  == Andrew Power Plant == 2 41 mW Generators, Operate 4hrs/day Monday-Friday
P1    80   82000       1       3       0       0      -2     1.2
P2   1.5    9800
PC     8       0     .45     .60     .65     .88     .92     .94     1.0
PF     8    .042    .042    .083    .083    .125    .167    .208     .25
PR     1       1       1       1       1     1.2     1.5     1.5     1.2       1
PR     1       1
PD     0       1       1       1       1       1       0
PH    24       0       0       0       0       0       0    .125    .125    .125
PH  .125    .125    .125    .125    .125       0       0       0       0       0
PH     0       0       0       0       0
PQ     0     203    4200    7500    9500   11600   32100   45000
PT   685     690   692.6   694.7   696.5   697.9   733.1     735
PP 28000   58000   68000   82000   82000   82000   82000
PS    80     100     115     125     130     145     200
C    PLANT EFFICIENCY RATIO IS (KW/CFS)
PE  6.75    6.75    6.97    7.42    7.64    7.86    8.08     8.3    8.52    8.75
PE  8.97    9.19    9.37     9.5     9.7     9.9   10.23   10.49   10.66   10.83
PE 11.00   11.16   11.31   11.47   11.62   11.78   11.93   12.09   12.24   12.40
PE 12.55   12.55
CP    80    9800
IDANDREW RESERVOIR
RT    80      70
CS     7       1      15     121     182     274     350     365
:
: Continued in Table E.2
```

Note that **PR** Records are also given. In this application, the **PR** data define monthly ratios to apply to the computed energy requirement defined by the storage-plant factor input. In this example, the ratio of one will be used from January to May, the first five months. Then in June, the ratio will be 1.2 and in July, 1.5. This allows for a seasonal increase, or decrease, in the energy requirements defined by the hydropower rule.

The **PD** Record distributes the weekly energy over the seven day. The input indicates a uniform demand over Monday through Friday. The **PH** Records serve to distribute the energy requirement over the block-hours of the day, 24 in this example. *Note, the number of hourly values must be the same for all power reservoirs in the model.* This input indicates a uniform demand from 7:00 AM to 2:00 PM.

The **PQ** and **PT** data defined the tailwater rating curve, flow versus tailwater. The data should define the entire range of potential releases, from low to high. The tailwater elevation will be computed by linear interpolation based on the average outflow for the time interval.

The **PP** and **PS** Records define the peaking capability as a function of storage, flow, or head, based on the code in field 4 of the **P1** Record. For this example, the data are based on head. The head, or storage, data should cover the entire range of operation.

The **PE** Records define hydropower efficiency as a function of storage defined on the **RS** Records. Based on the code in field 7 of the **P1** Record, either efficiency or kW per release (ft^3/s) is defined. In this example, it is the latter. For the 32 values of reservoir storage, the **PE** Record defines the $kW/ft^3/s$ factors. These factors are often computed to simplify hydropower calculations by hand. Given a power capacity, the required flow can be computed by dividing with the factor.

E.3.2 Peaking Energy Requirements

The input data for the east branch begins with Adam Reservoir illustrating specified energy requirements for a peaking hydropower project. The input data are shown in Table E.2. The reservoir (location 55) has seasonally varying storage for top-of-conservation, level 4. The nine seasons are defined on the **CS** Record, shown at the bottom of the table. Reservoir data includes area (**RA**), required for evaporation, and elevation (**RE**), required for hydropower computations. The maximum rate-of-change for releases, both increasing and decreasing, are defined on the **R2** Record.

Table E.2 Peaking Energy Requirements Data (continued from Table E.1)

```
: continued from Table E.1
:
C **************** Adam Reservoir **********************************************
RL    55 -1557.3
RL     1      55      -1         867600
RL     2      55      -1        1369772
RL     3      55      -1        1956000
RL     4      55       9        1957000 1957000 1957000 1957000 1995200 1995200
RL                              1995200 1957000 1957000
RL     5      55      -1        2554000
RL     6      55      -1        3070000
RO
RS   -39       0     760     867     913     960    1009    1059    1085    1112
RS  1139    1166    1194    1222    1251    1280    1309    1339    1370    1401
RS  1432    1464    1496    1529    1561    1595    1629    1663    1698    1733
RS  1769    1805    1842    1879    1917    1957    1994    2034    2554    3070
RQ    39       0    1000    9750    9820    9870    9920    9970   10010   10050
RQ  9000    9000   10190   10230   10270   10300   10330   10370   10410   10450
RQ 10490   10530   10570   10610   10650   10690   10730   10770   10800   10830
RQ 10870   10910   10940   10980   11020   11060    9500    9500   11580   21850
RA    39       0   20508   22442   23217   24008   24833   25701   26159   26619
RA 27079   27535   27983   28432   28861   29291   29721   30153   30587   31023
RA 31461   31901   32343   32789   33238   33690   34147   34610   35079   35555
RA 36036   36522   37015   37515   38024   38542   39078   39638   47182   53300
RE    39    1420    1530    1535    1537    1539    1541    1543    1544    1545
RE  1546    1547    1548    1549    1550    1551    1552    1553    1554    1555
RE  1556    1557    1558    1559    1560    1561    1562    1563    1564    1565
RE  1566    1567    1568    1569    1570    1571    1572    1573    1585    1595
R2 12000   12000

C  == Adam Power Plant == 4 20 mW Generators, Operate 4hrs/day Monday-Friday
P1    55   80000    1.15       0  1433.6      50     .87     1.5
P2   2.3    9000
PR-.0595  -.0595  -.0595  -.1192  -.1192  -.1192  -.1192   -.089   -.089   -.089
PR-.0595  -.0595
PD     0      .2      .2      .2      .2      .2       0
PH    24       0       0       0       0       0       0     .25     .25     .25
PH   .25       0       0       0       0       0       0       0       0       0
PH     0       0       0       0       0
CP    55   15000
IDADAM RESERVOIR
RT    55      50
CS     9       1      32      60      90     121     181     273     335     365
:
: Continued in Table E.3
```

The hydropower data begin with the **P1** Record, which defines for location 55: the installed capacity, the overload ratio, and a constant capacity will be used (fields 1 through 4, respectively). Following those are: the tailwater elevation, the downstream reservoir for tailwater consideration, the efficiency, and a fixed head loss in feet. When the tailwater is multiply defined, the program will use the higher value for each time step. That is, the input tailwater elevation of 1433.6 will be used if higher than the pool elevation at location 50. The **P2** Record defines the leakage as 2.3 ft^3/s and the penstock capacity as 9000 ft^3/s.

The monthly energy requirements are defined on the **PR** Records. The negative sign indicates that the input is plant factor rather than energy. The energy requirements are computed by multiplying the plant factor times installed capacity times the duration of the month, in hours. The **PD** Record defines the daily distribution, Sunday through Saturday. The daily data indicates a uniform distribution of energy for Monday through Friday and no power requirements for the weekend. For the hourly simulation, the **PH** Records define the distribution during the day, starting with the number of values, 24. This indicates the following data is hourly, starting from midnight. *(Note for **PH** Records, all power reservoirs must have the same number of values.)* The hourly data define four hours of operation from 1 to 4 PM each weekday, as the comment information (**C** Record) states. The monthly plant factor 0.1192 is equivalent to operating the full 80,000 KW plant capacity for four hours per week day. (This will be shown in the output review for this example.)

E.3.3 Run-of-river Hydropower Data

The run-of-river data and the remainder of the input file are listed in Table E.3. The re-regulation dam, location 50, regulates the flow from Adam Reservoir and operates to meet flow goals at location 33 (**RO** Record). The lower reservoir has the same basic reservoir data as the others, with fewer data points and a constant storage for each level. The power data are similar too, except this project has a tailwater rating curve (**PQ** and **PT** Records) and there are no energy requirements on the **PR** Records.

The power data (**P1** Record) define a 6,000 MW capacity with a 1.2 overload factor, an 0.85 efficiency, and a 1.1 foot head loss. There is no **P2** Record, which is optional. The **PR** Records are required; however, the blank fields indicate that there are no energy requirements. This means that the reservoir will make releases for other purposes and the energy resulting from the release will be computed.

Looking at the reservoir **RO** Record indicates the reservoir operates for itself and downstream location 33. At the reservoir, there is a minimum desired flow requirement of 130 ft^3/s and a required flow of 25 ft^3/s (**CP** Record). The downstream location, Willeyburg, has a monthly minimum-flow schedule (**QM** Records). This means that the primary operation for the re-regulation reservoir will be to ensure that the minimum flow target at Willeyburg is met and to generate energy, up to the limit of its capacity, with the reservoir releases.

Table E.3 Run-of-river Hydropower Data (continued from Table E.2)

```
: continued from Table E.2
:

C ***************** Reregulation Dam below Adam Reservoir *********************
RL    50   11400     290    1500    1600   17500   18500   19300
RO     1      33
RS     6     290     750    4000   11000   17500   19300
RQ     6       0   11900   46900   72749   85905   87400
RA     6      50      80     610     787     870     890
RE     6    1407    1414    1424    1434    1442    1444
R2  3000    4000
C  == Reregulation Dam Power Plant, 6,000 kW, Run of River Operation ===========
P1    50    6000     1.2                             .85     1.1
PR
PR
PQ    20     100     400     800    1200    2000    5000   10000   20000
PT1400.2 1400.55 1401.27 1401.92 1402.45 1403.33 1405.75  1408.7 1413.11
CP    50   16000     120      35
IDREREG
RT    50      33

CP    70  999999
IDOTTOVILLE
RT    70      33

C **************** Green River at Willeyburg ***********************************
CP    33  999999
IDWILLEYBURG
RT    33
QM   755     925     950    1550    1600    1650    1700    1450    1400    1400
QM   755     755

ED
BF     2      48               86073100               1                     1900
ZR=IN80  A=ROCK RIVER   B=ANDREW RESERVOIR C=LOCAL FLOW  F=COMPUTED
ZR=IN70  A=ROCK RIVER   B=OTTOVILLE        C=LOCAL FLOW  F=COMPUTED
ZR=IN55  A=GREEN RIVER  B=ADAM RESERVOIR   C=LOCAL FLOW  F=COMPUTED
ZR=IN50  A=GREEN RIVER  B=REREG RESERVOIR  C=LOCAL FLOW  F=COMPUTED
ZR=IN33  A=GREEN RIVER  B=WILLEYBURG       C=LOCAL FLOW  F=COMPUTED
EJ
ER
```

*Note: Both this reservoir and Andrew Reservoir, location 80, operate for the downstream flow goal at location 33. When two reservoirs operate for the same downstream location, the reservoir at the higher level is given the priority to meet the downstream goal. This reservoir only has 1,000 acre-feet of storage between levels 4 and 5 (***RL*** Record). Location 80 has a variable storage allocation; however, it is always over 290,000 acre-feet. With the larger storage between Levels 4 and 5 at location 80, that reservoir will tend to provide more of the flow required to meet the downstream goal at 33. In system operations, the reservoirs are considered balanced when they are at the same level. To be balanced from Levels 5 to 4, Adam Reservoir would draw-down 290,000 acre-feet while the re-regulation reservoir draws down 1,000 acre-feet. The output review in Section E.3.6 describes this reservoirs operation.*

The flow data indicates 48 periods of one-hour flow will be processed, starting on 31 July 1986. Note: the century input is in field 10 of the **BF** Record. The flow data will be read from a DSS file based on the defined pathnames parts defined on the **ZR** Records.

E.3.4 Power Guide Curve Output

The first user table provides an overview of the entire reservoir system. Reservoir Case and Outflow shows the releases and the controlling purpose. For the two storage projects, the Case is mostly leakage (Case = 0.13) and hydropower generation based on energy requirement (Case = 0.10). And exception is Case - 0.14 for Adam Reservoir at 0800 and 0900 on 31 July. That indicates that the penstock capacity is limiting. Adam Reservoir operation is reviewed in Section E.3.5. The re-regulation operation is either for downstream flow goal (Case = 33.00) or at-site minimum flow (Case = 0.00) The re-regulation reservoir is reviewed in Section E.3.6.

Andrew Reservoir operation is presented in User Table 2, Figure E.5. Along with Case and Outflow are: Level, Energy Generated, Energy Required and Plant Factor. The hourly distribution for energy was for eight hours per week-day, starting at 0700. The input plant factor (**PF** Record) for 0.88 storage (Level = 2.88) is 0.125. However, the monthly multiplier (**PR** Records) is 1.25 for July and August. Therefore, the energy requirement is the product of the two values, making the required plant factor 0.1875. The output Plant Factor shows 0.19 for the eight periods a day of energy generation. When there is no energy requirement, the release is 1.50 ft^3/s and the Case is 0.13. Both consistent with the input leakage of 1.5 ft^3/s. The energy requirement gradually decreases for each period because the reservoir is at a lower storage level. The program interpolates the plant factor based on the power storage for each period. By the second day, the power storage is 87% (Level = 2.87).

Table E.4 Hydropower Example User Table 1

*USERS. 1   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Per	Date:	Hr	Day	ANDREW RE Case	ANDREW RE Outflow	ADAM RESE Case	ADAM RESE Outflow	REREG Case	REREG Outflow	WILLEYBUR Flow Reg	WILLEYBUR Min Desi
Location No=				80.	80.	55.	55.	50.	50.	33.	33.
J8/JZ Codes=				80.120	80.100	55.120	55.100	50.120	50.100	33.040	33.050
1	31Jul86	1	Thu	0.13	1.50	0.13	2.30	33.00	1441.05	1700.00	1700.00
2	31Jul86	2	Thu	0.13	1.50	0.13	2.30	33.00	1440.26	1699.98	1700.00
3	31Jul86	3	Thu	0.13	1.50	0.13	2.30	33.00	1439.49	1700.00	1700.00
4	31Jul86	4	Thu	0.13	1.50	0.13	2.30	33.00	1438.72	1700.00	1700.00
5	31Jul86	5	Thu	0.13	1.50	0.13	2.30	33.00	1437.91	1699.98	1700.00
6	31Jul86	6	Thu	0.13	1.50	0.13	2.30	33.00	1437.13	1699.97	1700.00
7	31Jul86	7	Thu	0.10	1416.74	0.10	8897.90	0.00	120.00	1798.86	1700.00
8	31Jul86	8	Thu	0.10	1415.99	0.10	8966.13	0.00	120.00	1798.89	1700.00
9	31Jul86	9	Thu	0.10	1415.25	0.14	9002.30	0.00	120.00	1798.93	1700.00
10	31Jul86	10	Thu	0.10	1414.50	0.14	9002.30	0.00	120.00	1798.96	1700.00
11	31Jul86	11	Thu	0.10	1413.75	0.13	2.30	0.00	120.00	1798.99	1700.00
12	31Jul86	12	Thu	0.10	1413.01	0.13	2.30	0.00	120.00	1799.02	1700.00
13	31Jul86	13	Thu	0.10	1412.27	0.13	2.30	0.00	120.00	1799.07	1700.00
14	31Jul86	14	Thu	0.10	1411.53	0.13	2.30	0.00	120.00	1799.10	1700.00
15	31Jul86	15	Thu	0.13	1.50	0.13	2.30	33.00	1430.14	1699.99	1700.00
16 - 23 *deleted. The operation stays the same for the remainder of the day*											
:											
24	31Jul86	24	Thu	0.13	1.50	0.13	2.30	33.00	1423.13	1700.00	1700.00
25	1Aug86	1	Fri	0.13	1.50	0.13	2.30	33.00	1173.19	1449.99	1450.00
26	1Aug86	2	Fri	0.13	1.50	0.13	2.30	33.00	1172.71	1449.98	1450.00
27	1Aug86	3	Fri	0.13	1.50	0.13	2.30	33.00	1172.25	1450.00	1450.00
28	1Aug86	4	Fri	0.13	1.50	0.13	2.30	33.00	1171.76	1450.00	1450.00
29	1Aug86	5	Fri	0.13	1.50	0.13	2.30	33.00	1171.27	1449.98	1450.00
30	1Aug86	6	Fri	0.13	1.50	0.13	2.30	33.00	1170.81	1450.00	1450.00
31	1Aug86	7	Fri	0.10	1410.74	0.10	6730.70	0.00	120.00	1808.91	1450.00
32	1Aug86	8	Fri	0.10	1410.01	0.10	6730.70	0.00	120.00	1808.65	1450.00
33	1Aug86	9	Fri	0.10	1409.28	0.10	6730.70	0.00	120.00	1808.41	1450.00
34	1Aug86	10	Fri	0.10	1408.56	0.10	6730.70	0.00	120.00	1808.17	1450.00
35	1Aug86	11	Fri	0.10	1407.83	0.13	2.30	0.00	120.00	1807.91	1450.00
36	1Aug86	12	Fri	0.10	1407.11	0.13	2.30	0.00	120.00	1807.67	1450.00
37	1Aug86	13	Fri	0.10	1406.38	0.13	2.30	0.00	120.00	1807.41	1450.00
38	1Aug86	14	Fri	0.10	1405.66	0.13	2.30	0.00	120.00	1807.18	1450.00
39	1Aug86	15	Fri	0.13	1.50	0.13	2.30	33.00	1166.50	1450.00	1450.00
40 - 47 *deleted. The operation stays the same for the remainder of the day*											
48	1Aug86	24	Fri	0.13	1.50	0.13	2.30	33.00	1162.20	1450.00	1450.00

Table E.5 Andrew Reservoir Operation, User Table 2

*USERS. 2   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Location No=				80.	80.	80.	80.	80.	80.
J8/JZ Codes=				80.120	80.100	80.130	80.160	80.150	80.350
				ANDREW RE	ANDREW RE	ANDREW RE	ANDREW RE	ANDREW RE	ANDREW RE
Per	Date:	Hr	Day	Case	Outflow	Level	Energy G	Energy R	Plant Fa
1	31Jul86	1	Thu	0.13	1.50	2.88	0.00	0.00	0.00
2	31Jul86	2	Thu	0.13	1.50	2.88	0.00	0.00	0.00
3	31Jul86	3	Thu	0.13	1.50	2.88	0.00	0.00	0.00
4	31Jul86	4	Thu	0.13	1.50	2.88	0.00	0.00	0.00
5	31Jul86	5	Thu	0.13	1.50	2.88	0.00	0.00	0.00
6	31Jul86	6	Thu	0.13	1.50	2.88	0.00	0.00	0.00
7	31Jul86	7	Thu	0.10	1416.74	2.88	15333.75	15333.75	0.19
8	31Jul86	8	Thu	0.10	1415.99	2.88	15324.44	15324.44	0.19
9	31Jul86	9	Thu	0.10	1415.25	2.88	15315.13	15315.13	0.19
10	31Jul86	10	Thu	0.10	1414.50	2.88	15305.83	15305.83	0.19
11	31Jul86	11	Thu	0.10	1413.75	2.88	15296.53	15296.53	0.19
12	31Jul86	12	Thu	0.10	1413.01	2.88	15287.24	15287.24	0.19
13	31Jul86	13	Thu	0.10	1412.27	2.88	15277.95	15277.95	0.19
14	31Jul86	14	Thu	0.10	1411.53	2.88	15268.66	15268.66	0.19
15	31Jul86	15	Thu	0.13	1.50	2.88	0.00	0.00	0.00
16	31Jul86	16	Thu	0.13	1.50	2.88	0.00	0.00	0.00
17	31Jul86	17	Thu	0.13	1.50	2.88	0.00	0.00	0.00
18	31Jul86	18	Thu	0.13	1.50	2.88	0.00	0.00	0.00
19	31Jul86	19	Thu	0.13	1.50	2.88	0.00	0.00	0.00
20	31Jul86	20	Thu	0.13	1.50	2.88	0.00	0.00	0.00
21	31Jul86	21	Thu	0.13	1.50	2.88	0.00	0.00	0.00
22	31Jul86	22	Thu	0.13	1.50	2.88	0.00	0.00	0.00
23	31Jul86	23	Thu	0.13	1.50	2.88	0.00	0.00	0.00
24	31Jul86	24	Thu	0.13	1.50	2.88	0.00	0.00	0.00
25	1Aug86	1	Fri	0.13	1.50	2.88	0.00	0.00	0.00
26	1Aug86	2	Fri	0.13	1.50	2.88	0.00	0.00	0.00
27	1Aug86	3	Fri	0.13	1.50	2.88	0.00	0.00	0.00
28	1Aug86	4	Fri	0.13	1.50	2.88	0.00	0.00	0.00
29	1Aug86	5	Fri	0.13	1.50	2.88	0.00	0.00	0.00
30	1Aug86	6	Fri	0.13	1.50	2.88	0.00	0.00	0.00
31	1Aug86	7	Fri	0.10	1410.74	2.87	15258.74	15258.74	0.19
32	1Aug86	8	Fri	0.10	1410.01	2.87	15249.61	15249.61	0.19
33	1Aug86	9	Fri	0.10	1409.28	2.87	15240.50	15240.50	0.19
34	1Aug86	10	Fri	0.10	1408.56	2.87	15231.39	15231.39	0.19
35	1Aug86	11	Fri	0.10	1407.83	2.87	15222.30	15222.30	0.19
36	1Aug86	12	Fri	0.10	1407.11	2.87	15213.22	15213.22	0.19
37	1Aug86	13	Fri	0.10	1406.38	2.87	15204.14	15204.14	0.19
38	1Aug86	14	Fri	0.10	1405.66	2.87	15195.08	15195.08	0.19
39	1Aug86	15	Fri	0.13	1.50	2.87	0.00	0.00	0.00
40	1Aug86	16	Fri	0.13	1.50	2.87	0.00	0.00	0.00
41	1Aug86	17	Fri	0.13	1.50	2.87	0.00	0.00	0.00
42	1Aug86	18	Fri	0.13	1.50	2.87	0.00	0.00	0.00
43	1Aug86	19	Fri	0.13	1.50	2.87	0.00	0.00	0.00
44	1Aug86	20	Fri	0.13	1.50	2.87	0.00	0.00	0.00
45	1Aug86	21	Fri	0.13	1.50	2.87	0.00	0.00	0.00
46	1Aug86	22	Fri	0.13	1.50	2.87	0.00	0.00	0.00
47	1Aug86	23	Fri	0.13	1.50	2.87	0.00	0.00	0.00
48	1Aug86	24	Fri	0.13	1.50	2.87	0.00	0.00	0.00
		Sum =		5.76	22626.61	137.99	244224.50	244224.50	3.04
		Max =		0.13	1416.74	2.88	15333.75	15333.75	0.19
		Min =		0.10	1.50	2.87	0.00	0.00	0.00
		PMax=		1.00	7.00	1.00	7.00	7.00	7.00
		Avg =		0.12	471.39	2.87	5088.01	5088.01	0.06
		PMin=		7.00	1.00	38.00	1.00	1.00	1.00

E.3.5 Peaking Hydropower Output

Users Table 3 shows the operation of Adam Reservoir for hydropower demands. The output is shown in Table E.6, with minor editing to fit the page. Recalling that the reservoir operates four hours each week-day for hydroelectric energy, the initial six periods (hours) show an outflow of 2.30 ft^3/s and a case of 0.13. The case indicates the release is for leakage, as defined. There is no energy required.

For periods 7 through 10, the release is to meet hydropower demand. The Case = 0.10 indicates hydropower release. However, for periods 9 and 10, the Case is 0.14 indicating that the penstock capacity (9,000 ft^3/s) is limiting hydropower release. The outflow is 9,002.3 ft^3/s, which represents the penstock capacity plus the leakage of 2.3 ft^3/s. (Leakage is assumed to be continuous.) After the four hours of hydropower operation, the release is zero plus leakage.

The other data in Users. 3 are: Reservoir Level, Energy Generated, Energy Required, and Plant Factor. You can see by the Energy Generated during periods 9 and 10 did not equal requirement due to the penstock-limited release. The cause is the decrease in power head, due to the low pool level.

The second day of the simulation, August 1, has a different energy requirement and downstream low-flow goal. Again the reservoir operates for hydropower, starting at 7:00 am. With the lower energy demand, the reservoir is able to meet the demand with releases from 6,733 to 6,851 ft^3/s. Because these releases are well within the penstock limit, the cases all indicate 0.10 for these four periods and the energy required is met. Also, the plant factors indicate 0.75, which is consistent with three of the four units running.

When the hydropower requirements are zero, the reservoir release is zero and the only outflow is the leakage value of 2.3 ft^3/s and the Case is 0.13 for the rest of the day.

Table E.6 Adam Reservoir Operation, User Table 3

*USERS. 3   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Location No=				55.	55.	55.	55.	55.	55.
J8/JZ Codes=				55.120	55.100	55.130	55.160	55.150	55.350
				ADAM RES	ADAM RES	ADAM RES	ADAM RES	ADAM RES	ADAM RES
Per	Date:	Hr	Day	Case	Outflow	Level	Energy G	Energy R	Plant Fa
1	31Jul86	1	Thu	0.13	2.30	2.18	0.00	0.00	0.00
2	31Jul86	2	Thu	0.13	2.30	2.18	0.00	0.00	0.00
3	31Jul86	3	Thu	0.13	2.30	2.18	0.00	0.00	0.00
4	31Jul86	4	Thu	0.13	2.30	2.18	0.00	0.00	0.00
5	31Jul86	5	Thu	0.13	2.30	2.18	0.00	0.00	0.00
6	31Jul86	6	Thu	0.13	2.30	2.18	0.00	0.00	0.00
7	31Jul86	7	Thu	0.10	8897.90	2.18	80000.00	80000.00	1.00
8	31Jul86	8	Thu	0.10	8966.13	2.17	80000.00	80000.00	1.00
9	31Jul86	9	Thu	0.14	9002.30	2.17	79711.48	80000.00	1.00
10	31Jul86	10	Thu	0.14	9002.30	2.17	79097.59	80000.00	0.99
11	31Jul86	11	Thu	0.13	2.30	2.17	0.00	0.00	0.00
12	31Jul86	12	Thu	0.13	2.30	2.17	0.00	0.00	0.00
13	31Jul86	13	Thu	0.13	2.30	2.17	0.00	0.00	0.00
14	31Jul86	14	Thu	0.13	2.30	2.17	0.00	0.00	0.00
15	31Jul86	15	Thu	0.13	2.30	2.17	0.00	0.00	0.00
16	31Jul86	16	Thu	0.13	2.30	2.17	0.00	0.00	0.00
17	31Jul86	17	Thu	0.13	2.30	2.17	0.00	0.00	0.00
18	31Jul86	18	Thu	0.13	2.30	2.17	0.00	0.00	0.00
19	31Jul86	19	Thu	0.13	2.30	2.17	0.00	0.00	0.00
20	31Jul86	20	Thu	0.13	2.30	2.17	0.00	0.00	0.00
21	31Jul86	21	Thu	0.13	2.30	2.17	0.00	0.00	0.00
22	31Jul86	22	Thu	0.13	2.30	2.17	0.00	0.00	0.00
23	31Jul86	23	Thu	0.13	2.30	2.17	0.00	0.00	0.00
24	31Jul86	24	Thu	0.13	2.30	2.17	0.00	0.00	0.00
25	1Aug86	1	Fri	0.13	2.30	2.17	0.00	0.00	0.00
26	1Aug86	2	Fri	0.13	2.30	2.17	0.00	0.00	0.00
27	1Aug86	3	Fri	0.13	2.30	2.17	0.00	0.00	0.00
28	1Aug86	4	Fri	0.13	2.30	2.17	0.00	0.00	0.00
29	1Aug86	5	Fri	0.13	2.30	2.17	0.00	0.00	0.00
30	1Aug86	6	Fri	0.13	2.30	2.17	0.00	0.00	0.00
31	1Aug86	7	Fri	0.10	6733.80	2.17	59808.00	59808.00	0.75
32	1Aug86	8	Fri	0.10	6772.42	2.17	59808.01	59808.00	0.75
33	1Aug86	9	Fri	0.10	6811.72	2.17	59808.01	59808.00	0.75
34	1Aug86	10	Fri	0.10	6851.71	2.17	59808.01	59808.00	0.75
35	1Aug86	11	Fri	0.13	2.30	2.17	0.00	0.00	0.00
36	1Aug86	12	Fri	0.13	2.30	2.17	0.00	0.00	0.00
37	1Aug86	13	Fri	0.13	2.30	2.17	0.00	0.00	0.00
38	1Aug86	14	Fri	0.13	2.30	2.17	0.00	0.00	0.00
39	1Aug86	15	Fri	0.13	2.30	2.17	0.00	0.00	0.00
40	1Aug86	16	Fri	0.13	2.30	2.17	0.00	0.00	0.00
41	1Aug86	17	Fri	0.13	2.30	2.17	0.00	0.00	0.00
42	1Aug86	18	Fri	0.13	2.30	2.17	0.00	0.00	0.00
43	1Aug86	19	Fri	0.13	2.30	2.17	0.00	0.00	0.00
44	1Aug86	20	Fri	0.13	2.30	2.17	0.00	0.00	0.00
45	1Aug86	21	Fri	0.13	2.30	2.17	0.00	0.00	0.00
46	1Aug86	22	Fri	0.13	2.30	2.17	0.00	0.00	0.00
47	1Aug86	23	Fri	0.13	2.30	2.17	0.00	0.00	0.00
48	1Aug86	24	Fri	0.13	2.30	2.17	0.00	0.00	0.00
		Sum =		6.08	63130.30	104.26	558041.06	559232.00	6.99
		Max =		0.14	9002.30	2.18	80000.00	80000.00	1.00
		Min =		0.10	2.30	2.17	0.00	0.00	0.00
		PMax=		9.00	9.00	1.00	7.00	7.00	7.00
		Avg =		0.13	1315.21	2.17	11625.86	11650.67	0.15
		PMin=		7.00	1.00	34.00	1.00	1.00	1.00

E.3.6 Run-of-river Hydropower Output

The Re-Regulation Reservoir output is shown in Users. 4, listed in Table E.7. Again, the upper reservoir, Adam, only operates for hydropower four hours during the five week-days. The lower, re-regulation, reservoir operates for downstream flow goals and incidently produces hydropower. There is no required energy at this site.

The Case variable shows 33.00 or 0.00 for all periods. Location 33 is the downstream location Willeyburg. The reservoir is operating for the downstream location and, during July, the flow goal is 1,700 ft^3/s and in August the goal is 1,450 ft^3/s. Looking back to User 1, Table E.4, during the first six periods the Flow Regulated at Willeyburg is 1700 ft^3/s. Then during the next eight periods the regulated flow is greater than 1700 ft^3/s. Also note, during those periods Andrew reservoir is releasing for hydropower. With that information, the release schedule for the re-regulation reservoir makes sense. When Andrew Reservoir operates for hydropower, the re-regulation reservoir only needs to make a small release to meet the flow goal at Willeyburg. However, the minimum release is 120 ft^3/s. Therefore, during the eight hours of power releases on the West Branch, the reservoir operates for its minimum release. The remaining hours, the re-regulation reservoir operates for location 33 because there are no power releases on the other branch.

The Level and Energy Generated shows the affect of the hydropower cycle on the East Branch. The inflow to the re-regulation reservoir comes exclusively from the upper reservoir release. Therefore, the inflow is the leakage value of 2.3 ft^3/s until the hydropower is generated for four hours. During generation, the inflow exceed the required outflow to meet downstream demand and the pool level rises. Then, with the higher pool level, the energy generated is greater for approximately the same release. During the remaining time, the release draws the pool level down. As the pool draws down, the energy generated decreases. The weekend operation, with no hydropower release, will be most critical for the re-regulation dam to meet the downstream demand with essentially no inflow. This simulation does not extend into the weekend.

Table E.7 Re-Regulation Reservoir Operation, User Table 4

*USERS. 4 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Location No=				50.	50.	50.	50.	50.	50.
J8/JZ Codes=				50.120	50.100	50.130	50.160	50.150	50.350
				REREG	REREG	REREG	REREG	REREG	REREG
Per	Date:	Hr	Day	Case	Outflow	Level	Energy G	Energy R	Plant Fa
1	31Jul86	1	Thu	33.00	1441.05	3.61	3171.36	0.00	0.53
2	31Jul86	2	Thu	33.00	1440.26	3.60	3154.53	0.00	0.53
3	31Jul86	3	Thu	33.00	1439.49	3.59	3137.78	0.00	0.52
4	31Jul86	4	Thu	33.00	1438.72	3.59	3120.71	0.00	0.52
5	31Jul86	5	Thu	33.00	1437.91	3.58	3101.49	0.00	0.52
6	31Jul86	6	Thu	33.00	1437.13	3.57	3082.35	0.00	0.51
7	31Jul86	7	Thu	0.00	120.00	3.62	279.26	0.00	0.05
8	31Jul86	8	Thu	0.00	120.00	3.66	286.99	0.00	0.05
9	31Jul86	9	Thu	0.00	120.00	3.71	294.77	0.00	0.05
10	31Jul86	10	Thu	0.00	120.00	3.76	302.57	0.00	0.05
11	31Jul86	11	Thu	0.00	120.00	3.75	306.41	0.00	0.05
12	31Jul86	12	Thu	0.00	120.00	3.75	306.31	0.00	0.05
13	31Jul86	13	Thu	0.00	120.00	3.75	306.20	0.00	0.05
14	31Jul86	14	Thu	0.00	120.00	3.75	306.10	0.00	0.05
15	31Jul86	15	Thu	33.00	1430.14	3.75	3423.40	0.00	0.57
16	31Jul86	16	Thu	33.00	1429.36	3.74	3406.67	0.00	0.57
17	31Jul86	17	Thu	33.00	1428.58	3.73	3389.97	0.00	0.56
18	31Jul86	18	Thu	33.00	1427.80	3.72	3373.29	0.00	0.56
19	31Jul86	19	Thu	33.00	1427.00	3.72	3356.59	0.00	0.56
20	31Jul86	20	Thu	33.00	1426.25	3.71	3340.02	0.00	0.56
21	31Jul86	21	Thu	33.00	1425.47	3.70	3323.42	0.00	0.55
22	31Jul86	22	Thu	33.00	1424.69	3.69	3306.84	0.00	0.55
23	31Jul86	23	Thu	33.00	1423.89	3.69	3290.25	0.00	0.55
24	31Jul86	24	Thu	33.00	1423.13	3.68	3273.74	0.00	0.55
25	1Aug86	1	Fri	33.00	1173.19	3.67	2711.36	0.00	0.45
26	1Aug86	2	Fri	33.00	1172.71	3.67	2700.26	0.00	0.45
27	1Aug86	3	Fri	33.00	1172.25	3.66	2689.20	0.00	0.45
28	1Aug86	4	Fri	33.00	1171.76	3.65	2678.10	0.00	0.45
29	1Aug86	5	Fri	33.00	1171.27	3.65	2667.03	0.00	0.44
30	1Aug86	6	Fri	33.00	1170.81	3.64	2656.00	0.00	0.44
31	1Aug86	7	Fri	0.00	120.00	3.68	290.26	0.00	0.05
32	1Aug86	8	Fri	0.00	120.00	3.71	296.06	0.00	0.05
33	1Aug86	9	Fri	0.00	120.00	3.75	301.86	0.00	0.05
34	1Aug86	10	Fri	0.00	120.00	3.78	307.66	0.00	0.05
35	1Aug86	11	Fri	0.00	120.00	3.78	310.51	0.00	0.05
36	1Aug86	12	Fri	0.00	120.00	3.78	310.41	0.00	0.05
37	1Aug86	13	Fri	0.00	120.00	3.78	310.30	0.00	0.05
38	1Aug86	14	Fri	0.00	120.00	3.78	310.20	0.00	0.05
39	1Aug86	15	Fri	33.00	1166.50	3.77	2858.28	0.00	0.48
40	1Aug86	16	Fri	33.00	1166.03	3.77	2847.24	0.00	0.47
41	1Aug86	17	Fri	33.00	1165.55	3.76	2836.19	0.00	0.47
42	1Aug86	18	Fri	33.00	1165.07	3.75	2825.16	0.00	0.47
43	1Aug86	19	Fri	33.00	1164.59	3.75	2814.14	0.00	0.47
44	1Aug86	20	Fri	33.00	1164.11	3.74	2803.12	0.00	0.47
45	1Aug86	21	Fri	33.00	1163.63	3.73	2792.13	0.00	0.47
46	1Aug86	22	Fri	33.00	1163.13	3.73	2781.08	0.00	0.46
47	1Aug86	23	Fri	33.00	1162.66	3.72	2770.13	0.00	0.46
48	1Aug86	24	Fri	33.00	1162.20	3.72	2759.23	0.00	0.46
		Sum =		056.00	43496.33	177.83	101266.91	0.00	16.87
		Max =		33.00	1441.05	3.78	3423.40	0.00	0.57
		Min =		0.00	120.00	3.57	279.26	0.00	0.05
		PMax=		1.00	1.00	34.00	15.00	1.00	15.00
		Avg =		22.00	906.17	3.70	2109.73	0.00	0.35
		PMin=		7.00	7.00	6.00	7.00	1.00	7.00

E.4 Pumped-Storage

The pumped storage capability in HEC-5 is applicable to either an adjacent (off stream) or integral (pump-back) configuration. The energy available for pumping is input. Based on the available energy, the program computes the pumped discharge for each time step, subject to storage capacity, available water and flow constraints. Example 8 modifies the re-regulation reservoir from Example 7 into a pump-back reservoir model operating with the upstream Adam Reservoir. The following sections describe the data input and output.

E.4.1 Pumped-Storage Data

To model a pump in a hydropower system, a dummy reservoir is added, just upstream from the upper reservoir, to describe the pumping capabilities. The pump data from Example 8 are shown in Table E.8. Basic reservoir and control point data are required for dummy reservoir (as shown for Reservoir 155). The reservoir has no storage allocated, operates for no downstream locations, and has an unlimited outlet capacity.

Table E.8. Pump-back Data from Example 8

```
T1      HEC-5 Example 8, Pumped Storage Hydropower Model   (EXAMPLE8.DAT)
T2      Pumped Storage with Re-Regulation Reservoir and Downstream Flow Goal
T3      Green River, Adam Reservoir to Willeyburg, 3-Hour Flow Data
J1     0       1       5       3       4       2
J2    24       1
J3     4                                      -1
J8 55.16   55.15   55.35   55.13   55.12   55.10   50.13   50.12   50.10   10.04
J8155.15  155.16  155.00  155.03   55.09   55.10   50.09   50.10
JZ 55.13   50.13   55.16   55.23  155.15  155.16   55.10   50.10   10.04
C =================== Pumpback at Adam Reservoir ==============================
RL   155
RO
RS     2       1     100
RQ     2     100      -1
RE     2       1      10
C  == Adam Reservoir Pumpback == 1 24 mW Pump Unit =============================
P1   155  -24000       1                      50     .75     2.1
P2     0    5500
PR -.375   -.375   -.375   -.375   -.375   -.375   -.375   -.375   -.375   -.375
PR -.375   -.375
C  ==  Energy Available 9hrs/day (8 pm - 5 am) Sunday - Saturday ===============
PD  .142    .143    .143    .143    .143    .143    .143
PH     8  0.3333  0.2223       0       0       0       0  0.1111  0.3333
CP   155  999999
IDPUMPBACK
RT   155      55
DR   155      50       0       0       0       0      -3
C =================== Adam Reservoir (Pumped Storage Project) =================
```

The power data for a pump is indicated by a negative capacity (-24,000 kW) in the second field of the **P1** Record for the pump-back data. The program "knows" that the input power data are for pumping, not generation. The tailwater should be based on the lower reservoir (the pumping supply source), which is the re-regulation reservoir at location 50, defined in field 6. (The minimum tailwater elevation can be specified in field 5.) The efficiency is the pumping efficiency (e.g., 0.75 input in field 7). A fixed head loss for pumping is input in field 8 (e.g., 2.1 feet). The optional **P2** Record, in fields 1 and 2, defines no leakage and a pumping penstock capacity of 5,500 ft^3/s.

The energy available to pump is input to the program as monthly plant factors on the **PR** Records. The plant factors are based on the number of hours per day that energy is available for pumping. For pumped-storage simulation with daily or multiple-hourly time intervals, **PD** and **PH** Records should also be used. In Example 8, the daily distribution is uniform, **PD** Records. The eight three-hour blocks of hourly distribution, on the **PH** Record, show energy is available during the first two and last two blocks of time. The ratios represent 0.3333 for all three hours, 0.22223 for two hours and 0.1111 for one hour. Thus, the data suggests that energy is available from 8 PM to 5 AM, as stated on the Comment Record.

Control point data include the **RT** Record, which indicates the dummy routes to the upper reservoir (e.g., Reservoir 55) with no routing lag. A diversion record (**DR**) is required to convey the pump-back discharge into the upper reservoir. The diversion record is input with the dummy reservoir data. The diversion is indicated from the dummy (Reservoir 155) to the downstream source of water (Reservoir 50). The diversion type is -3 (**DR** Record, field 7) for pump-back simulation. The computed pump-back discharges are carried by the program as diversions from Reservoir 50 to Reservoir 155. The diversions are then routed into Reservoir 55 based on an unlimited outlet capacity and zero lag routing criteria.

In the HEC-5 simulation, water will be pumped to the upper reservoir using all the available energy; however pumping will stop if the upstream pool reaches the top-of-conservation level or the lower pool draws below the buffer level. The maximum pump-back level can be set to a lower level than the top-of-conservation pool by defining an intermediate pump-back level on the **J1** Record, field 7.

The pump-back reservoir’s data, for the power generation cycle of operation, follows the pumping data defined at the "dummy" reservoir. Adams Reservoir, location 55, data are the same as the data in Example 7, described in the previous Hydropower Model. The input is shown in Table E.8. Minor differences include the hourly distribution of power requirements are defined in eight 3-hour blocks instead of 24 hourly values. Remember that all **PH** Records must have the same number of values in an HEC-5 model. Also, while the starting storage is input in the **RL** Record, the actual starting storage is input with the time-series data on **SS** Records, shown at the end of Table E.10.

Table E.9. Pump-back Data from Example 8 (continued)

```
: Continued from Table E.8
:
C ==================== Adam Reservoir (Pumped Storage Project) ==================
RL    55 1995200
RL     1      55      -1         867600
RL     2      55       9        1369772 1400771 1400771 1400771 1400771 1400771
RL                              1400771 1400771 1369772
RL     3      55       9        1957000 1957000 1957000 1957000 1995200 1995200
RL                              1995200 1957000 1957000
RL     4      55      -1        2554000
RL     5      55      -1        3070000
RO
RS   -39       0     760     867     913     960    1009    1059    1085    1112
RS  1139    1166    1194    1222    1251    1280    1309    1339    1370    1401
RS  1432    1464    1496    1529    1561    1595    1629    1663    1698    1733
RS  1769    1805    1842    1879    1917    1957    1994    2034    2554    3070
RQ    39       0    1000    9750    9820    9870    9920    9970   10010   10050
RQ  9000    9000   10190   10230   10270   10300   10330   10370   10410   10450
RQ 10490   10530   10570   10610   10650   10690   10730   10770   10800   10830
RQ 10870   10910   10940   10980   11020   11060    9500    9500   11580   21850
RA    39       0   20508   22442   23217   24008   24833   25701   26159   26619
RA 27079   27535   27983   28432   28861   29291   29721   30153   30587   31023
RA 31461   31901   32343   32789   33238   33690   34147   34610   35079   35555
RA 36036   36522   37015   37515   38024   38542   39078   39638   47182   53300
RE    39    1420    1530    1535    1537    1539    1541    1543    1544    1545
RE  1546    1547    1548    1549    1550    1551    1552    1553    1554    1555
RE  1556    1557    1558    1559    1560    1561    1562    1563    1564    1565
RE  1566    1567    1568    1569    1570    1571    1572    1573    1585    1595
R2 12000   12000
R3  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
R3  -0.8    -1.6
C  == Adam Power Plant == 4 20 MW Generators ===================================
P1    55   80000    1.15       0  1433.6      50     .87     1.5
P2   2.3    9000
PR-.0893  -.0893  -.0893  -.1786  -.1786  -.1786  -.1786   -.134   -.134   -.134
PR-.0893  -.0893
C  ==  Required Generation 6hrs/day (6am - 12 noon) Monday - Friday ============
PD     0      .2      .2      .2      .2      .2       0
PH     8       0       0      .5      .5       0       0       0       0
CP    55   15000
IDADAM RESERVOIR
RT    55      50
CS     9       1      32      60      90     121     181     273     335     365
 :
```

The re-regulation reservoir, location 50, is immediately below Adam Reservoir, the pump-back reservoir. This reservoir is the source for pump-back water, as described above. The data are listed in Table E.10. As in Example 7, the reservoir does not have specified power requirements, the **PR** Records are blank. The reservoir operates for its own minimum flow of 100 ft^3/s and the downstream location 10 flow-goal of 1,100 ft^3/s. The energy generated will be computed based on the releases made for other purposes.

Table E.10. Pump-back Data from Example 8 (continued)

```
: Continued from Table E.9
:

C ***************** Re-Regulation Dam below Adam Reservoir ********************
RL    50    1500     290    1500   17500   18500   19300
RO     1      10
RS     6     290     750    4000   11000   17500   19300
RQ     6       0   11900   46900   72749   85905   87400
RA     6      50      80     610     787     870     890
RE     6    1407    1414    1424    1434    1442    1444
R3  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
R3  -0.8    -1.6
C  == Re-Regulation Dam Power Plant, 6,000 kW, Run of River Operation ==========
P1    50    6000     1.2                             .85     1.1
PR
PR
PQ    20     100     400     800    1200    2000    5000   10000   20000
PT1400.2 1400.55 1401.27 1401.92 1402.45 1403.33 1405.75  1408.7 1413.11
CP    50   17500     100
IDREREG
RT    50      10

C **************** Green River at Willeyburg ************************************
CP    10  999999    1100
IDWILLEYBURG
RT    10

ED
BF     2      56             86050500             3                   1900
SS    55-1571.35
SS    50 -1428.1
ZR=IN55  A=GREEN RIVER  B=ADAM RESERVOIR   C=LOCAL FLOW  F=COMPUTED
ZR=IN50  A=GREEN RIVER  B=REREG            C=LOCAL FLOW  F=COMPUTED
ZR=IN10  A=GREEN RIVER  B=WILLEYBURG       C=LOCAL FLOW  F=COMPUTED
ZW      A=EXAMPLE 8  F=PUMPED STORAGE SIMULATION
EJ
ER
```

The downstream location, Willeyburg, has the target flow of 1,100 ft^3/s. This location ends the reservoir model.

The time-series data (**BF**) indicates 56 periods starting on 5 May 1986 with 3-hour data. The starting storage for locations 55 and 50 is defined with **SS** Records and the negative values indicate reservoir elevation, rather than storage. The flow data are read from DSS records, as defined by input pathnames. Output data written to DSS will have EXAMPLE 8 as the A-part and PUMPED STORAGE SIMULATION as the F-Part, **ZW** Record.

E.4.2 Pumped-Storage Output

The User. 1 table shows the operation of Adam Reservoir and the re-regulation reservoir. The first three days, 24 periods, are listed in Table E.11. The output shows Adam Reservoir operating for hydropower two periods each day, the re-regulation reservoir operating for location 10, and 1,100 ft^3/s at that location.

Table E.11 Pump-back Operation, Users Table 1

```
*USERS. 1    User Designed Output    (Dates shown are for END-of-Period)

                                           Summary by Period   Flood=       1
Location No=           55.        55.        55.       55.       55.       55.       50.       50.       50.        10.
J8/JZ Codes=           55.160     55.150     55.350    55.130    55.120    55.100    50.130    50.120    50.100     10.040

                    ADAM RES    ADAM RES  ADAM RES  ADAM RES  ADAM RES ADAM RES   REREG     REREG     REREG      WILLEYBUR
 Per  Date:  Hr Day   Energy G    Energy R  Plant Fa  Level      Case     Outflow   Level     Case     Outflow     Flow Reg

   1  5May86  3 Mon       0.00        0.00      0.00      2.96      0.13      2.30     2.30    10.00     955.31    1100.00
   2  5May86  6 Mon       0.00        0.00      0.00      2.96      0.13      2.30     2.27    10.00     958.14    1100.00
   3  5May86  9 Mon  240000.02   240000.00      1.00      2.96      0.10   7980.21     2.38    10.00     965.59    1100.00
   4  5May86 12 Mon  240000.00   240000.00      1.00      2.95      0.10   7983.28     2.49    10.00     973.03    1100.00
   5  5May86 15 Mon       0.00        0.00      0.00      2.95      0.13      2.30     2.48    10.00     980.47    1100.00
   6  5May86 18 Mon       0.00        0.00      0.00      2.95      0.13      2.30     2.46    10.00     987.92    1100.00
   7  5May86 21 Mon       0.00        0.00      0.00      2.95      0.13      2.30     2.44    10.00     995.36    1100.00
   8  5May86 24 Mon       0.00        0.00      0.00      2.95      0.13      2.30     2.40    10.00     995.26    1100.00
   9  6May86  3 Tue       0.00        0.00      0.00      2.95      0.13      2.30     2.36    10.00     995.16    1100.00
  10  6May86  6 Tue       0.00        0.00      0.00      2.95      0.13      2.30     2.33    10.00     995.06    1100.00
  11  6May86  9 Tue  240000.00   240000.00      1.00      2.95      0.10   7984.25     2.44    10.00     993.63    1100.00
  12  6May86 12 Tue  240000.02   240000.00      1.00      2.95      0.10   7987.33     2.55    10.00     992.20    1100.00
  13  6May86 15 Tue       0.00        0.00      0.00      2.95      0.13      2.30     2.54    10.00     990.77    1100.00
  14  6May86 18 Tue       0.00        0.00      0.00      2.95      0.13      2.30     2.52    10.00     989.34    1100.00
  15  6May86 21 Tue       0.00        0.00      0.00      2.95      0.13      2.30     2.50    10.00     987.91    1100.00
  16  6May86 24 Tue       0.00        0.00      0.00      2.95      0.13      2.30     2.47    10.00     989.04    1100.00
  17  7May86  3 Wed       0.00        0.00      0.00      2.95      0.13      2.30     2.43    10.00     990.17    1100.00
  18  7May86  6 Wed       0.00        0.00      0.00      2.95      0.13      2.30     2.40    10.00     991.31    1100.00
  19  7May86  9 Wed  240000.02   240000.00      1.00      2.95      0.10   7988.27     2.51    10.00     986.33    1100.00
  20  7May86 12 Wed  240000.00   240000.00      1.00      2.94      0.10   7991.35     2.62    10.00     981.35    1100.00
  21  7May86 15 Wed       0.00        0.00      0.00      2.94      0.13      2.30     2.60    10.00     976.37    1100.00
  22  7May86 18 Wed       0.00        0.00      0.00      2.94      0.13      2.30     2.59    10.00     971.39    1100.00
  23  7May86 21 Wed       0.00        0.00      0.00      2.94      0.13      2.30     2.57    10.00     966.41    1100.00
  24  7May86 24 Wed       0.00        0.00      0.00      2.94      0.13      2.30     2.53    10.00     959.94    1100.00
   :
   : Periods 25 - 56 omitted
```

The pump-back operation and the continuity of flow is shown in User. 2, with the first 24 periods shown in Table E.12. There is no special output for pump-back operation; the basic hydropower variables and diversion are used. Looking at Table E.12, the "`PUMPBACK Energy R`" is the energy available for pumping. The "`Energy G`" is the energy used, not generated. The "`Change`" column is the difference between the preceding two columns. That column shows that the available energy was used for pumping. The water pumped back is shown as a negative diversion, "`PUMPBACK Diveriso`." A negative diversion indicates a gain instead of loss to the reservoir.

The Inflow to Adam Reservoir is the reservoir inflow plus the diversion. The outflow from Adam reflects the leakage value of 2.3 ft^3/s or the hydropower release for two periods each day.

The Inflow to the re-regulation reservoir is both negative and positive. The inflow is the net value, reflecting pump-back "diversions," local flow, and releases from Adam Reservoir. The outflow for the re-regulation dam is the release to meet the downstream flow goal, as noted in the review of User 1.

The third user table shows the reservoir levels, energy generated, energy used, the outflows and the resulting downstream regulated flow. The first 24 periods are listed in Table E.13. The Adam Reservoir level shows the advantage of pump-back operation. The releases for energy lower the pool level; however, the pump-back operation tends to recover the water and resupply Adam Reservoir.

The complement operation is shown in the re-regulation level. Releases from Adam raise the regulation reservoir level, while pump-back diversions and outflow lower the level. By balancing the pumping and generation cycles, the reservoir can maintain the downstream flow goal at Willeyburg and have sufficient water supply to pump to the limit of available energy. The critical time comes during the weekend when there are no power releases from Adam Reservoir. While not shown in the tables here, the re-regulation reservoir was able to meet the weekend operation for the simulation period. Review the complete output for Example 8 to see the full week operation.

Table E.12 Pump-back Operation, Users Table 2

*USERS. 2   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Location No=				155.	155.	155.	155.	55.	55.	50.	50.
J8/JZ Codes=				155.150	155.160	155.000	155.030	55.090	55.100	50.090	50.100
				PUMPBACK	PUMPBACK	PUMPBACK	PUMPBACK	ADAM RESE	ADAM RESE	REREG	REREG
Per	Date:	Hr	Day	Energy R	Energy G	Change	Diversio	Inflow	Outflow	Inflow	Outflow
1	5May86	3	Mon	72000.00	72000.00	0.00	-1463.82	1801.53	2.30	-1392.26	955.31
2	5May86	6	Mon	48064.82	48062.09	2.73	-971.51	1308.69	2.30	-900.08	958.14
3	5May86	9	Mon	0.00	0.00	0.00	0.00	336.97	7980.21	8049.21	965.59
4	5May86	12	Mon	0.00	0.00	0.00	0.00	336.76	7983.28	8052.17	973.03
5	5May86	15	Mon	0.00	0.00	0.00	0.00	336.55	2.30	71.09	980.47
6	5May86	18	Mon	0.00	0.00	0.00	0.00	336.34	2.30	70.99	987.92
7	5May86	21	Mon	24021.60	24021.31	0.29	-498.51	834.64	2.30	-427.60	995.36
8	5May86	24	Mon	72000.00	71997.48	2.52	-1488.78	1825.44	2.30	-1417.95	995.26
9	6May86	3	Tue	72000.00	71997.49	2.51	-1479.81	1816.99	2.30	-1409.05	995.16
10	6May86	6	Tue	48064.82	48063.72	1.10	-981.99	1319.70	2.30	-911.30	995.06
11	6May86	9	Tue	0.00	0.00	0.00	0.00	338.45	7984.25	8052.58	993.63
12	6May86	12	Tue	0.00	0.00	0.00	0.00	339.18	7987.33	8055.60	992.20
13	6May86	15	Tue	0.00	0.00	0.00	0.00	339.92	2.30	70.51	990.77
14	6May86	18	Tue	0.00	0.00	0.00	0.00	340.66	2.30	70.46	989.34
15	6May86	21	Tue	24021.60	24021.31	0.29	-503.90	845.29	2.30	-433.50	987.91
16	6May86	24	Tue	72000.00	71997.39	2.61	-1504.84	1847.97	2.30	-1434.49	989.04
17	7May86	3	Wed	72000.00	71997.41	2.59	-1495.62	1840.49	2.30	-1425.32	990.17
18	7May86	6	Wed	48064.82	48063.67	1.15	-992.40	1339.00	2.30	-922.16	991.31
19	7May86	9	Wed	0.00	0.00	0.00	0.00	348.34	7988.27	8056.14	986.33
20	7May86	12	Wed	0.00	0.00	0.00	0.00	350.08	7991.35	8059.15	981.35
21	7May86	15	Wed	0.00	0.00	0.00	0.00	351.81	2.30	70.02	976.37
22	7May86	18	Wed	0.00	0.00	0.00	0.00	353.55	2.30	69.93	971.39
23	7May86	21	Wed	24021.60	24021.30	0.29	-509.45	864.74	2.30	-439.62	966.41
24	7May86	24	Wed	72000.00	71997.36	2.64	-1521.39	1876.57	2.30	-1451.67	959.94

:
: *Periods 25 - 56 omitted*

Table E.13 Pump-back Operation, Users Table 3

*USERS. 3   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Location No=				55.	50.	55.	55.	155.	155.	55.	50.	10.
J8/JZ Codes=				55.130	50.130	55.160	55.230	155.150	155.160	55.100	50.100	10.040
				ADAM RESE	REREG	ADAM RESE	ADAM RESE	PUMPBACK	PUMPBACK	ADAM RESE	REREG	WILLEYBUR
Per	Date:	Hr	Day	Level	Level	Energy G	Energy S	Energy R	Energy G	Outflow	Outflow	Flow Reg
1	5May86	3	Mon	2.96	2.30	0.00	0.00	72000.00	72000.00	2.30	955.31	1100.00
2	5May86	6	Mon	2.96	2.27	0.00	0.00	48064.82	48062.09	2.30	958.14	1100.00
3	5May86	9	Mon	2.96	2.38	240000.02	0.00	0.00	0.00	7980.21	965.59	1100.00
4	5May86	12	Mon	2.95	2.49	240000.00	0.00	0.00	0.00	7983.28	973.03	1100.00
5	5May86	15	Mon	2.95	2.48	0.00	0.00	0.00	0.00	2.30	980.47	1100.00
6	5May86	18	Mon	2.95	2.46	0.00	0.00	0.00	0.00	2.30	987.92	1100.00
7	5May86	21	Mon	2.95	2.44	0.00	0.00	24021.60	24021.31	2.30	995.36	1100.00
8	5May86	24	Mon	2.95	2.40	0.00	0.00	72000.00	71997.48	2.30	995.26	1100.00
9	6May86	3	Tue	2.95	2.36	0.00	0.00	72000.00	71997.49	2.30	995.16	1100.00
10	6May86	6	Tue	2.95	2.33	0.00	0.00	48064.82	48063.72	2.30	995.06	1100.00
11	6May86	9	Tue	2.95	2.44	240000.00	0.00	0.00	0.00	7984.25	993.63	1100.00
12	6May86	12	Tue	2.95	2.55	240000.02	0.00	0.00	0.00	7987.33	992.20	1100.00
13	6May86	15	Tue	2.95	2.54	0.00	0.00	0.00	0.00	2.30	990.77	1100.00
14	6May86	18	Tue	2.95	2.52	0.00	0.00	0.00	0.00	2.30	989.34	1100.00
15	6May86	21	Tue	2.95	2.50	0.00	0.00	24021.60	24021.31	2.30	987.91	1100.00
16	6May86	24	Tue	2.95	2.47	0.00	0.00	72000.00	71997.39	2.30	989.04	1100.00
17	7May86	3	Wed	2.95	2.43	0.00	0.00	72000.00	71997.41	2.30	990.17	1100.00
18	7May86	6	Wed	2.95	2.40	0.00	0.00	48064.82	48063.67	2.30	991.31	1100.00
19	7May86	9	Wed	2.95	2.51	240000.02	0.00	0.00	0.00	7988.27	986.33	1100.00
20	7May86	12	Wed	2.94	2.62	240000.00	0.00	0.00	0.00	7991.35	981.35	1100.00
21	7May86	15	Wed	2.94	2.60	0.00	0.00	0.00	0.00	2.30	976.37	1100.00
22	7May86	18	Wed	2.94	2.59	0.00	0.00	0.00	0.00	2.30	971.39	1100.00
23	7May86	21	Wed	2.94	2.57	0.00	0.00	24021.60	24021.30	2.30	966.41	1100.00
24	7May86	24	Wed	2.94	2.53	0.00	0.00	72000.00	71997.36	2.30	959.94	1100.00

:

: *Periods 25 - 56 ommited*

E.5 System Power Operation

When individual hydropower reservoirs deliver energy and capacity into a common power system, operating the projects as a system can often produce more energy or more firm energy than the sum of the individual projects operating independently. Many of the options available for at-site power are available for the system as well. Additional data requirements for the system power routines consist of system energy requirements and an indication at each hydropower plant if it is in the system.

At the beginning of each time-step of the simulation, the energy potential of all reservoirs in the system is estimated. This is accomplished by subdividing each reservoir in the system into multiple levels within the power pool. Then the energy produced by drawing each reservoir drawn to each level is computed and summed for all. Then the system energy required is compared to the total energy produced at each level to estimate the common level where all the reservoirs would meet the system energy requirement. By this method the system energy is allocated to the reservoirs in the system. If no other constraint applies, the reservoirs will each operate to meet the allocated system load and their storage should be at the same level at the end of the time step. By this approach, the system energy load is allocated to the projects most able to meet the demand for each time step.

The system power computations do not consider the time delay of water moving through the system. Therefore, the allocation of system energy may not balance with the actual flow releases when channel routing is used. Therefore, channel routing should not be used with system power options.

E.5.1 System Energy Data

System Energy Requirements. System requirements are defined for the entire system. Monthly system energy requirements are given in MWh on the **SM** Records. An alternative is to input monthly ratios and indicate the total annual system energy on the thirteenth field of the **SM** Record (third field of second record).

System energy requirements for each day of the week may be specified as a ratio on the **SD** Record. The program computes the weekly requirements based on the monthly energy requirement (**SM** Records) and then computes the daily values from the weekly requirements based on the **SD** Records. Seven daily ratios which must total 1.0 are given on the **SD** Record.

For simulations time-steps of less than one day, the multi-hourly system energy requirements are given on the **SH** Record. As with at-site power, the hourly distribution can be defined for an even interval of a day, up to 24 values for hourly. For example, if 6-hour flows were provided, four ratios are given on the **SH** Record, one for each six-hour routing interval of the day.

System Power Guide Curve. The power guide curve approach for a single reservoir can be applied to a system of reservoirs. The power storage in the system is the sum of each of the individual reservoir's power storage. The percent of the total power storage occupied in the reservoir system is entered on the **SC** Record as a ratio. The corresponding system plant factor is entered on the **SF** Record. When the cumulative storage in the system is between levels 2 and 3 (top-of-buffer to top-of-conservation pool), the guide curve will control operation. When the system storage is below level 2, the system will operate at the minimum plant factor corresponding to 0% power storage on the guide curve. (The power priority can be changed on the **J2**, field 4 to operate to Level 1.) When the **SC** Record is used, the **SM** Records are read as usual, but they represent monthly adjustment ratios of the plant factors on the **SF** Records. This method is an alternative method to firm system energy operation.

Firm Monthly Energy Requirements. At each hydropower reservoir in the model, all of the power data previously described are still provided plus an indication if the power plant is in the power system (**P2** Record, field 3) and the maximum plant factor for the project which can be used to meet the system load (**P2** Record, field 4).

E.5.2 System Energy Model

The system power model is Example 9. A listing of the first part of the input data file, including system energy data and the first reservoir in the system, is shown in Table E.14. This model is a modification of Example 7, the first hydropower example. Note the first **J8** record with system energy variables, 80.28, 80.26, and 80.29. The system energy output is associated with the first reservoir in the data model, reservoir 80 in this example.

The system power data are provided before the first reservoir. The general format is similar to at-site power requirements. The **SM** data provide the monthly energy requirements, in MWh, for all the reservoirs in the system. The thirteenth entry can be used as a multiplying factor, 1.0 in this example. The daily distribution of the system energy is defined on the **SD** Records, Sunday through Saturday. In this example, the daily distribution is uniform over the weekdays and none on the weekend.

The data for Reservoir 80 is the same as Example 7, except the at-site energy requirements were eliminated allowing the reservoir complete freedom to operate for the system load. If at-site requirements are defined, the reservoir will have to operate to meet those requirements as well as the allocated system demand. The additional input is the indicator that Andrew Reservoir is in the system (**P2** Record, field 3 = 1). Hydropower reservoirs do not have to be in the system.

The data for Adam Reservoir is the same as Example 7. The at-site power requirements were left, which means that Adam will operate to meet those requirements. The **P2** Record was modified (field 3 = 1) indicating that Adam is

Table E.14 System Hydropower Model (Example 9)

```
T1      HEC-5 Example 9, System Hydropower Model, Daily Flow Data (EXAMPLE9.DAT)
T2      2 Peaking Plants and a Re-Regulation Reservoir with Run-of-River Power
T3      Green and Rocky Rivers, Adam and Andrew Reservoirs to Willeyburg
J1     0       1       5       3       4       2
J2    24       1
J3     4                                       1
J6  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
J6  -0.8    -1.6
J8 80.13   55.13   50.13   80.16   55.16   50.16   80.28   80.26   80.00   80.29
J8 80.12   80.16   80.10   55.12   55.16   55.10   50.12   50.16   50.10   80.28
JZ-80.13   55.13   50.13   80.28   80.26   80.16   55.16   50.16
SM 12000   11500   10450   10500   10100   10500   15500   15700   12000   12500
SM 12500   12000     1.0
SD     0      .2      .2      .2      .2      .2       0

C =================== Andrew Reservoir (Peaking Project) =====================
RL    80  210492
RL     1      80      -1          82890
RL     2      80      -1          95000
RL     3      80       7         210492  210492  379611  379611  379611  210492
RL                               210492
RL     4      80      -1         670052
RL     5      80      -1         804006
RO
RS    32   10373   82884   89647  104879  113447  122709  132705  143514  155137
RS167612  181000  195280  210492  226656  243772  261860  280940  301031  322154
RS344288  367473  391749  417136  443713  471559  500734  531317  563427  597164
RS632646  670052  804006
RQ    32    9800    9800    9800    9800    9800    9800    9800    9800    9800
RQ  9800    9800    9800    9800    9800    9800    9800    9800    9800    9800
RQ  9800   15000   26000   37000   50000   66000   82000  100000  120000  140000
RQ160000  185000  300000
RA    32     182    3251    3516    4116    4452    4812    5196    5602    6024
RA  6462    6913    7373    7841    8317    8801    9293    9793   10298   10808
RA 11329   11862   12411   12988   13599   14246   14933   15665   16449   17293
RA 18206   19201   24200
RE    32     725     800     802     806     808     810     812     814     816
RE   818     820     822     824     826     828     830     832     834     836
RE   838     840     842     844     846     848     850     852     854     856
RE   858     860     870
R2 10000   10000
C  == Andrew Power Plant == 2 41 mW Generators,
P1    80   82000       1       3   696.8       0      -1     1.2
P2   1.5    9800       1
PR
PR
PQ     0     203    4200    7500    9500   11600   32100   45000
PT   685     690   692.6   694.7   696.5   697.9   733.1     735
PP 28000   58000   68000   82000   82000   82000   82000
PS    80     100     115     125     130     145     200
PE   .80     .81     .82     .82     .83     .83     .84     .84     .84     .84
PE   .85     .85     .85     .85     .85     .85     .86     .86     .86     .87
PE   .87     .87     .88     .88     .87     .86     .85     .85     .84     .84
PE   .84     .83
CP    80    9800
IDANDREW RESERVOIR
RT    80      70
CS     7       1      15     121     182     274     350     365
 : data model continues, see file Example9.dat
```

part of the system. Therefore, the program will consider the energy generated to meet at-site requirements as part of the system energy. If there is a limit on a reservoir's contribution to meet system load, the fourth field of the **P2** Record can be used to limit the maximum contribution for any hydropower project.

The re-regulation reservoir is also part of the system. There were no power requirements at that location in Example 7, so the reservoir generated power based on operation for low-flow goals. Now, being part of the system, the reservoir will operate to meet system goals as well as low-flow goals.

The flow data and simulation runs one-year of average daily flow. The following output review focuses on the first month; however, you can run the data and review the entire year.

E.5.3 System Energy Output

The output table for system energy is associated with the first reservoir in the hydropower system. Output options include system energy requirement, generation, usable energy and system shortage. The usable energy can be less than the system generated energy if the maximum system plant factor for each individual project (**P2** Record, field 4) is less than the maximum at-site plant factor for the project (overload ratio, **P1** Record, field 3).

Case output for hydropower operation shows Case = .10 when the reservoir is operating for at-site energy, and Case = .12 when the reservoir is generating for system energy production.

Table E.15 lists the first month from Example 9 Users Table 1. The output lists the reservoir Levels, Energy Generated for each reservoir, System Energy Generated and Required, plus the difference between and System Energy Shortage. While the last two columns are similar, the Shortage only shows deficiency from requirements while the difference shows any difference. For example, there is no energy required on Saturday and Sunday so there is no shortage. You can see from the shortages that the energy allocation process is not exact; however, the sum of the project energy production is very close to the target.

Looking at the first three columns of Level, shows the two storage reservoirs at nearly the same level while the re-regulation reservoir tends to be lower. Recall that the re-regulation reservoir also operates to meet downstream flow goals. A review of the Case variable should show the bases for releases. Table E.16 shows the Case, Energy Generated, and Outflow for each reservoir.

Table E.15 System Energy Operation, Users Table 2

*USERS. 2   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Location No=			80.	80.	80.	55.	55.	55.	50.	50.	50.	80.
J8/JZ Codes=			80.120	80.160	80.100	55.120	55.160	55.100	50.120	50.160	50.100	80.280
			ANDREW RE	ANDREW RE	ANDREW RE	ADAM RES	ADAM RES	ADAM RES	REREG	REREG	REREG	ANDREW RE
Period	Date:	Day	Case	Energy G	Outflow	Case	Energy G	Outflow	Case	Energy G	Outflow	Sys En G
1	1Jan86	Wed	0.12	228.39	1051.91	0.12	223.29	993.85	0.12	89.39	1369.99	541.07
2	2Jan86	Thu	0.12	172.80	796.49	0.12	260.81	1152.59	0.12	105.44	1679.67	539.05
3	3Jan86	Fri	0.12	163.72	754.99	0.12	268.10	1173.47	0.12	105.34	1745.53	537.16
4	4Jan86	Sat	0.03	15.83	74.31	0.13	0.00	2.30	0.00	7.58	120.00	23.40
5	5Jan86	Sun	0.03	112.58	519.23	0.13	0.00	2.30	0.00	7.52	120.00	120.10
6	6Jan86	Mon	0.12	220.44	1015.80	0.12	254.25	1096.63	0.12	63.97	1074.05	538.66
7	7Jan86	Tue	0.12	147.84	682.26	0.12	298.11	1286.49	0.12	90.14	1551.20	536.09
8	8Jan86	Wed	0.12	147.10	679.12	0.12	305.30	1311.60	0.12	83.68	1456.91	536.07
9	9Jan86	Thu	0.12	147.04	679.18	0.12	318.94	1367.09	0.12	71.52	1236.54	537.50
10	10Jan86	Fri	0.12	149.04	688.69	0.12	330.46	1420.50	0.12	59.69	1002.71	539.18
11	11Jan86	Sat	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.55	120.00	7.55
12	12Jan86	Sun	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.49	120.00	7.49
13	13Jan86	Mon	0.12	302.23	1394.17	0.12	202.92	876.45	0.12	35.31	577.18	540.46
14	14Jan86	Tue	0.12	150.88	697.63	0.12	358.31	1555.13	0.12	32.68	508.92	541.86
15	15Jan86	Wed	0.12	140.19	648.64	0.12	305.29	1352.48	0.12	95.84	1501.93	541.31
16	16Jan86	Thu	0.13	0.00	1.50	0.12	457.84	2022.67	0.12	166.35	2777.44	624.18
17	17Jan86	Fri	0.13	0.00	1.50	0.12	453.48	1976.52	0.12	151.06	2646.07	604.54
18	18Jan86	Sat	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.33	120.00	7.33
19	19Jan86	Sun	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.27	120.00	7.27
20	20Jan86	Mon	0.13	0.00	1.50	0.12	437.18	1874.87	0.12	98.78	1753.08	535.97
21	21Jan86	Tue	0.13	0.00	1.50	0.12	450.20	1936.28	0.12	87.95	1517.71	538.15
22	22Jan86	Wed	0.13	0.00	1.50	0.12	482.10	2091.00	0.12	59.81	958.83	541.92
23	23Jan86	Thu	0.13	0.00	1.50	0.12	407.13	1805.58	0.12	133.58	2164.02	540.71
24	24Jan86	Fri	0.13	0.00	1.50	0.12	378.78	1669.65	0.12	155.66	2676.95	534.45
25	25Jan86	Sat	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.37	120.00	7.37
26	26Jan86	Sun	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.32	120.00	7.32
27	27Jan86	Mon	0.13	0.00	1.50	0.12	429.19	1848.98	0.12	106.73	1903.00	535.92
28	28Jan86	Tue	0.13	0.00	1.50	0.12	423.65	1824.56	0.12	111.46	2012.25	535.11
29	29Jan86	Wed	0.13	0.00	1.50	0.12	452.23	1942.07	0.12	85.91	1510.80	538.13
30	30Jan86	Thu	0.13	0.00	1.50	0.12	482.70	2091.01	0.12	59.19	965.94	541.90
31	31Jan86	Fri	0.13	0.00	1.50	0.12	411.68	1823.22	0.12	129.17	2124.43	540.85

32 - *end of run not listed.*

Table E.16 System Energy Operation, Users Table 1

*USERS. 1   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood= 1

Location No=			80.	55.	50.	80.	55.	50.	80.	80.	80.	80.
J8/JZ Codes=			80.130	55.130	50.130	80.160	55.160	50.160	80.280	80.260	80.000	80.290
			ANDREW RE	ADAM RES	REREG	ANDREW RE	ADAM RES	REREG	ANDREW RE	ANDREW RE	ANDREW RE	ANDREW RE
Period	Date:	Day	Level	Level	Level	Energy G	Energy G	Energy G	Sys En G	Sys En R	Change	Sys En S
1	1Jan86	Wed	3.00	3.00	2.95	228.39	223.29	89.39	541.07	541.94	-0.87	0.87
2	2Jan86	Thu	3.00	3.00	2.89	172.80	260.81	105.44	539.05	541.94	-2.88	2.88
3	3Jan86	Fri	2.99	2.99	2.82	163.72	268.10	105.34	537.16	541.94	-4.77	4.77
4	4Jan86	Sat	3.00	2.99	2.80	15.83	0.00	7.58	23.40	0.00	23.40	0.00
5	5Jan86	Sun	3.00	2.99	2.79	112.58	0.00	7.52	120.10	0.00	120.10	0.00
6	6Jan86	Mon	2.99	2.99	2.79	220.44	254.25	63.97	538.66	541.94	-3.27	3.27
7	7Jan86	Tue	2.99	2.99	2.76	147.84	298.11	90.14	536.09	541.94	-5.84	5.84
8	8Jan86	Wed	2.98	2.98	2.74	147.10	305.30	83.68	536.07	541.94	-5.86	5.86
9	9Jan86	Thu	2.98	2.98	2.76	147.04	318.94	71.52	537.50	541.94	-4.44	4.44
10	10Jan86	Fri	2.98	2.98	2.81	149.04	330.46	59.69	539.18	541.94	-2.75	2.75
11	11Jan86	Sat	2.98	2.98	2.80	0.00	0.00	7.55	7.55	0.00	7.55	0.00
12	12Jan86	Sun	2.99	2.98	2.78	0.00	0.00	7.49	7.49	0.00	7.49	0.00
13	13Jan86	Mon	2.97	2.97	2.82	302.23	202.92	35.31	540.46	541.94	-1.48	1.48
14	14Jan86	Tue	2.97	2.97	2.95	150.88	358.31	32.68	541.86	541.94	-0.07	0.07
15	15Jan86	Wed	2.97	2.97	2.93	140.19	305.29	95.84	541.31	541.94	-0.62	0.62
16	16Jan86	Thu	2.96	2.96	2.84	0.00	457.84	166.35	624.18	541.94	82.25	0.00
17	17Jan86	Fri	2.95	2.95	2.76	0.00	453.48	151.06	604.54	541.94	62.60	0.00
18	18Jan86	Sat	2.95	2.96	2.74	0.00	0.00	7.33	7.33	0.00	7.33	0.00
19	19Jan86	Sun	2.95	2.96	2.73	0.00	0.00	7.27	7.27	0.00	7.27	0.00
20	20Jan86	Mon	2.94	2.95	2.74	0.00	437.18	98.78	535.97	541.94	-5.97	5.97
21	21Jan86	Tue	2.94	2.95	2.80	0.00	450.20	87.95	538.15	541.94	-3.79	3.79
22	22Jan86	Wed	2.93	2.94	2.94	0.00	482.10	59.81	541.92	541.94	-0.02	0.02
23	23Jan86	Thu	2.93	2.93	2.89	0.00	407.13	133.58	540.71	541.94	-1.23	1.23
24	24Jan86	Fri	2.92	2.93	2.77	0.00	378.78	155.66	534.45	541.94	-7.49	7.49
25	25Jan86	Sat	2.92	2.93	2.75	0.00	0.00	7.37	7.37	0.00	7.37	0.00
26	26Jan86	Sun	2.91	2.93	2.74	0.00	0.00	7.32	7.32	0.00	7.32	0.00
27	27Jan86	Mon	2.91	2.93	2.73	0.00	429.19	106.73	535.92	541.94	-6.01	6.01
28	28Jan86	Tue	2.91	2.92	2.71	0.00	423.65	111.46	535.11	541.94	-6.83	6.83
29	29Jan86	Wed	2.90	2.92	2.76	0.00	452.23	85.91	538.13	541.94	-3.80	3.80
30	30Jan86	Thu	2.90	2.91	2.90	0.00	482.70	59.19	541.90	541.94	-0.04	0.04
31	31Jan86	Fri	2.89	2.90	2.87	0.00	411.68	129.17	540.85	541.94	-1.09	1.09

32 - *end of run not listed.*

The simulation starts on Wednesday and the first three Case values are 0.12 for the three reservoirs. This indicates that the three were operating for system power on Wednesday through Friday. On the weekend, with no system energy requirement, the reservoirs tend to operate for their local demands: Andrew Reservoir spilled (Case = 0.03), Adam Reservoir outflow is leakage (Case = 0.13) and the re-regulation reservoir released minimum flow (Case = 0.00). The pattern is the same for the following week.

During the third week, the pattern persists until period 16, when the case for Andrew changes to leakage (Case = 0.13). Referring back to User Table 1, the Levels for Andrew and Adam look balanced (equal). However, looking several periods later you can see that Adam's Level is higher than Andrew's. Because Adam is higher, the system energy is being allocated to it and Andrew's energy is being set to zero, only leakage. Recall that Andrew has no at-site power requirements so the energy production can go to zero.

The Case for the re-regulation reservoir indicates that it too is operating for the system load; however, the Level is not balanced with Adam. Two things are contributing to the imbalance: the minimum releases on the weekend and the relative small size of the re-regulation reservoir. With less storage, the re-regulation reservoir Level changes quickly with releases while the larger storage reservoirs change more slowly. It is difficult to balance a small storage reservoir with large reservoirs. However, the Levels remain fairly close.

For a more complete review of Example 9, run the data and review the output file. Generally, the energy requirements were met through the year and the minimum pool level was above 2.0 for all reservoirs.

E.6 Hydropower Determination

The objective of many hydropower planning studies is to determine how much firm energy can be produced given a reservoir of fixed size and installed capacity with a specified flow sequence (critical period). The solution is an iterative process of assuming different firm energy requirements until the maximum is found that can be generated with no shortages during the critical period. The inverse problem is also common. Given a fixed energy requirement, what is the minimum storage which will produce this amount? In this case, the storage is varied until a minimum is reached which will produce the required energy.

The HEC-5 optimization routines can handle the above tasks as well as a variety of water supply planning problems. Up to four reservoir locations not in tandem may be optimized in a single run. The time interval is normally monthly, but can be weekly or daily as long as the number of periods (NPER, **BF** Record, field 2) will fit into the HEC-5 program's memory as a single flow sequence. The number of periods that the routines can handle is a function of the program's Dynamic Dimension DM array size, which is set at compilation time, and the size of the data set (i.e., number of reservoirs and control points). The program will put an explanatory message specifying the maximum number of periods (NPER) which can be handled by the optimization routines if an insufficient memory situation occurs.

Options available for selecting the simulation period include: period-of-record, partial record and critical period. Unless otherwise requested in the input, the program simulates system operation for the entire period of the given inflow data. Refer to HEC-5 Users Manual Input Description for **J7** Record, field 8..

E.6.1 Capacity and Energy Determination

Capacity and energy determination is similar to yield determination, described in Section 4.6 and demonstrated in Section D.3. Job Record **J7** requests the optimization routine. Field 1 tells the program which reservoir to use (entered to the left of the decimal) and the optimization option selected (entered to the right of the decimal). The monthly energy requirements and the installed capacity of the power plant can be optimized for the given power storage. For example, at Reservoir 20, a value of 20.1 is coded in field 1 of the **J7** Record.

The values for optimization variables CRITPR, IFLAG, and OPTERR, are input on the **J7** Record in fields 8, 9, and 10 respectively. These variables deal with defining the critical period used in the optimization routine, checking to see if this is the true critical period, and the allowable error in the solution (usually 5%). The recommended values should normally be used.

The energy generated is proportioned according to the monthly plant factors on the **PR** Records. The program makes the initial estimate of capacity if the **P1** Record, field 2 equals 1. This indicates that this project is a proposed plant and not an existing plant. The estimate of capacity is based on the energy which could be produced from the power storage and the inflow during the estimated critical drawdown period. The length of the critical drawdown period is estimated by a routine based on an empirical relationship between drawdown, duration (in months) and the ratio of power storage to mean annual flow.

Alternately, the initial value of the capacity may be input in field 2 of the **P1** Record.

A summary output table shows the result from each optimization trial. First the results are shown for each iteration with the initial estimated critical period. Once an answer is found, the program will test it with the entire record. If it fails to meet energy production for the entire record, a new critical period is determined and the cycle continues with that period. Up to three full cycles can be performed. In the final trial, if the computed error ratio for the critical drawdown period is less than the specified allowable error, then no more iterations are needed.

E.6.2 Maximum Energy Determination

To request the maximum energy for the existing installed capacity, a value of 20.5 (reservoir 20 and option .5) is coded in field 1 of the **J7** Record. The existing capacity is given in field 2 of the **P1** Record. In the optimization, the capacity is held fixed while the firm energy is optimized. The final computed error ratio is below the specified allowable error (5%).

E.6.3 Power Storage Determination

To optimize power storage, field 1 is coded with a 20.0 (reservoir 20 and option 0). The installed capacity and energy requirements as plant factors are given as previously described on the power records.

In this option, the top-of-buffer pool remains fixed and the top-of-the conservation storage is varied until the maximum energy is produced for the given installed capacity.

The optimization routine will converge on a solution within the specified tolerance. The optimization routine adds 500,000 acre-feet to all storages to eliminate working with negative storage values. The true storage is equal to the storage shown in the output at level 3.0 less 500,000 acre-feet. A negative value of allowable error (**J7** Record, field 10) would perform one more simulation and remove the added 500,000 acre-feet and provide correct reservoir storages and levels.

E.6.4 Short-interval Analysis

A weekly, daily, or multi-hourly optimization of plant capacity and energy can be performed, similar to the monthly simulation. The flow data would be in the appropriate time interval. All other input data would be the same as monthly optimization. Given the shorter time interval, the results should be more accurate than those from a monthly simulation.